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Brain Myths Exploded
Lessons from Neuroscience

Course Guidebook

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University of San Francisco;
San Francisco Conservatory of Music

PUBLISHED BY:

THE GREAT COURSES
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4840 Westfields Boulevard, Suite 500
Chantilly, Virginia 20151-2299
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www.thegreatcourses.com

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Indre Viskontas is an Adjunct Professor of Psychology at the University of San Francisco and a Professor of Sciences and Humanities at the San Francisco Conservatory of Music, where she is pioneering the application of neuroscience to musical training. She received her bachelor of science degree with a specialty in Psychology and a minor in French Literature at Trinity College in the University of Toronto. Dr. Viskontas also holds a master of music degree in Vocal Performance from the San Francisco Conservatory of Music. She completed her Ph.D. in Cognitive Neuroscience at the University of California, Los Angeles (UCLA), where she studied the neural basis of memory and reasoning. Her postdoctoral work at the University of California, San Francisco, explored the paradoxical facilitation of creativity in patients with neurodegenerative diseases.

Dr. Viskontas's research is characterized by innovation and a focus on the big questions in neuroscience: How do brain cells code memory? What brain changes foster creativity? How can neuroscience help us train musicians more effectively? Defying traditional career boundaries, Dr.

Viskontas spends much of her time performing as an opera singer, with favorite recent roles including both Susanna and the Countess in Mozart's *Le Nozze di Figaro*, the title role in Gilbert and Sullivan's *Iolanthe*, Lazuli in Chabrier's *L'Etoile*, the title role in Floyd's *Susannah*, Micaëla in Bizet's *Carmen*, and Beth in Adamo's *Little Women*—with companies such as West Bay Opera, Opera on Tap, the Lyric Theatre of San Jose, the Banff Summer Arts Festival, Pasadena Opera, and others. She often works with composers and has created roles in 3 contemporary operas. Dr. Viskontas is the founder and director of Vocallective, a consortium of singers and instrumentalists dedicated to the art of vocal chamber music, as well as Opera on Tap: San Francisco, a chapter of the nationwide organization whose mission is to create a place for opera in popular culture by producing high-quality performances in nontraditional venues, such as art galleries, bars, and cafés.

Dr. Viskontas's dissertation was recognized as the best of her class. She has also been the recipient of numerous scholarships, fellowships, and awards, including a 4-year Julie Payette-NSERC Research Scholarship awarded to the top 10 Canadian graduate students in the life sciences, the Dr. Ursula Mandel Scholarship, a UCLA dissertation fellowship, the Charles E. and Sue K. Young Award for the top graduate students at UCLA, a McBean Family Foundation Fellowship, and the prestigious Laird Cermak Award from the Memory Disorders Research Society. Dr. Viskontas also received the Distinguished Teaching Assistant Award at UCLA and served as the teaching assistant consultant in the Department of Psychology, instructing other graduate students on effective teaching from 2003 to 2005. In her first term at the University of San Francisco, her students chose her to be the professor of the month. She has also received several grants from the Germanacos Foundation for her work on music and empathy.

Dr. Viskontas has published more than 40 original papers and book chapters related to the neural basis of memory, reasoning, and creativity in top scientific journals, such as *American Scientist*, *Proceedings of the National Academy of Sciences*, *The Journal of Neuroscience*, *Neuropsychologia*, *Current Opinion in Neurology*, and *Nature Clinical Practice*. Her scientific work was featured in Oliver Sacks's book *Musicophilia: Tales of Music and the Brain*, *Nature: Science Careers*, and *Discover* magazine. A sought-

after science communicator, Dr. Viskontas is a cocreator and cohost of the popular science podcast *Inquiring Minds*, which reached more than 5 million downloads within 3 years. She also cohosted the 6-episode docuseries *Miracle Detectives* on the Oprah Winfrey Network and has appeared on *The Oprah Winfrey Show* as well as on major radio stations across the United States, including several appearances on the NPR program *City Arts & Lectures* and *The Sunday Edition* on CBC Radio in Canada. Dr. Viskontas regularly gives keynote talks for conferences and organizations as diverse as Ogilvy & Mather, Genentech, and the Dallas Symphony Orchestra. She is a fellow of the Committee for Skeptical Inquiry and an editor of the journal *Neurocase*.

Dr. Viskontas's other Great Course is *12 Essential Scientific Concepts*. ■

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BRAIN MYTHS EXPLODED

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We are repeatedly told that one of the keys to a meaningful life is understanding why we do the things we do. Why is it, then, that so many myths about how our brains function persist? Why are our own minds so often misunderstood by their inhabitants? Is it just that the brain is too complicated? Will we ever grasp how it works, or is that understanding simply beyond our intellectual abilities? These are the questions that this course is designed to address.

As the pace of neuroscience research quickens and the sheer volume of findings explodes, it has never been more important to separate fact from fiction, reality from hyperbole. We are entering an age in which knowing ourselves will not only satisfy our intellectual curiosity, but will give us the tools to reach amazing heights, as we begin to use this knowledge to stave off diseases, develop expertise, and surpass previous generations in feats of all kinds. And this revolution is coming not a minute too soon, as so many more of us attain old age and the problems we face on this planet reach epic proportions.

The course will address both myths and mysteries of the brain, exchanging outdated or outright incorrect ideas for cutting-edge insights. Along the way, you will wonder at this magnificently complex organ, from which emerges our every experience, emotion, and intention. You will use one of our most powerful cognitive tools—the ability to recognize patterns—to understand how tiny cells, with their binary electrochemical signals, can provide us with the ability to love one another, master the violin, imagine any kind of future, and engage our brains in seemingly infinite ways.

The course will start with the raw material that our brains are made of and will uncover how ideas such as bigger brains make for smarter people, or psychiatric illnesses result from chemical imbalances, are misguided. Then, you will explore how one thing that we take for granted—that our perceptions represent an objective reality—needs to be reexamined. The truth is much more interesting. Next, you will delve into issues related to the part of our minds that we think we know most intimately—our consciousness—and learn just how deceptive our inner interpreter can be. Finally, you will learn about change: how the brain is much more malleable that we once thought, but not without biological limitations. Understanding how our brains change with experience can provide us with the tools to shape them into the machines that we wish they would be. ■

1

IS YOUR BRAIN PERFECTLY DESIGNED?

Many people have called the human brain—with its 86 billion neurons and hundreds of trillions of connections—the most complex thing in the universe. But with all its complexity, power, and beauty, it can also be messy, random, and inefficient. As you will learn throughout this course, once we cut through the various myths about the brain, we find that the facts are often more amazing than any fiction we could invent.

THE COMPLEXITY OF THE BRAIN

- The most basic myth about the brain is the deep-seated intuition that the brain is a masterpiece of neural design. The brain is highly complex, but it is simply the end result of millions of years of evolution. Every complexity in our brains arose from a very long history of tiny tweaks—which are still in progress. And some of these tweaks are more akin to inefficient hacks than to universal upgrades.

- These hacks are both frustrating and wonderful. They are responsible for our sievelike memory, the errors we make when we perceive the world and our snap judgments. But they also give us imagination, the delight of discovering illusions, and our uncanny ability to find patterns in everything.

- To understand the hacks that nature has applied to our brains, we need to consider our path through millions of years of evolution.

But it's very difficult to find definitive evidence for the evolution of specific psychological traits or neuroanatomy. We can only make inferences based on what we can see. For some answers, we can also look to the brains and behaviors of other animals and to the similarities and differences between our fellow humans.

> It's far too tempting to look to evolution for a good story and to be taken in by a compelling explanation that our minds developed "just so." This type of thinking feeds the myth that natural selection had a design in mind all the while.

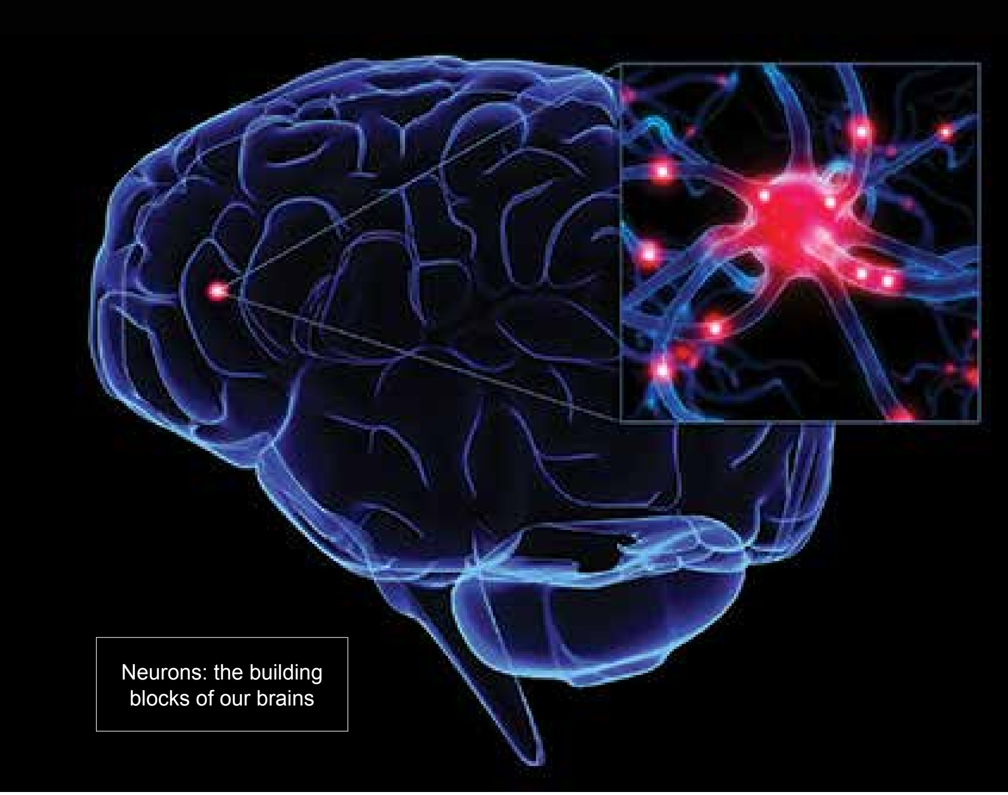
VARIABILITY

> When it comes to the adaptive but imperfect design of our brains, the material nature had to work with were cells. In the brain, these cells are called neurons. Our neurons point to the less-than-perfect process out of which the human brain emerged.

> Natural selection is the process by which some traits, which are written into our genetic code, afford some advantage to those who possess them. These lucky people must then leave behind more children than their less gifted counterparts for the trait to proliferate.

> Without variability in a population, however, there is no opportunity for natural selection to operate. If we're all the same, with respect to a particular trait, there's no way that Mother Nature can favor some people over others. So, our diversity is the key to the long-term survival of our species.

> This variability and diversity is evident even among neurons, the building blocks of our brains. Neurons have different sizes and shapes, different baseline firing rates, different types of connections, and different responses to the chemicals involved in cell signaling (neurotransmitters).



Neurons: the building blocks of our brains

- Neurons have 3 basic parts: dendrites, which receive information; the cell body, which contains all the things the cell needs to survive and reproduce; and the axon, which sends information on to other cells.

- For some neurons, the receiving end interacts directly with the outside world, as is the case in our eyes. These types of neurons will generally have fairly simple receptive parts. But other neurons are not so simple.

- The morphology—the size and shape of neurons—is one variable that evolution has to work with. The length of connections—how far or near a neuron's signal goes—is another variable.

- Some neurons send information only over very short distances, within the same brain region. Then there are neurons whose axons travel from one end of the brain to another, joining together different brain regions and forming networks that allow us to synthesize information from different senses or use information from our eyes and ears to make decisions about what to do next.

- This variability in our neurons and these differences are related to the different roles these neurons have in the brain. Some neurons distinguish colors from one another, while others power your muscles. Some are involved in complex cognition, such as deciding which political party to vote for, while others lie down new long-term memories.

- But a neuron cannot control what it does or does not do. This issue lies at the heart of one of the biggest philosophical questions: How does the mind, which gives us at least the feeling that we can control our actions, emerge from billions of cells that themselves have no control over their own actions?

- Here's where we turn back to Mother Nature for the answers. Both the tiny, local interneurons and the large, complex neurons are found in other animals, such as monkeys and mice. And the cerebellum has an analogue in most other animals with a nervous system. So, the complexity of the human brain, though impressive, is an emergent property of the many, many small changes that occurred at every branch of our ancestral tree.

EVOLUTION

- There are a few different types of neurons that seem to play roles in functions such as fine motor coordination, social interactions, and self-awareness, but they are also present in other animals, and they might have arisen through successive tweaking of the basic neuron. Natural selection ended up with a hacked set of new cells, not a carefully designed foundation on which to build a perfect brain.

> Even so, when we consider the sophisticated way by which neurons communicate, it's once again difficult to imagine how they might have evolved from the single-celled organisms that were the very beginnings of life. How does a bacterium turn into a neuron?

> But the answer is actually fairly simple. The stuff of cells is encased in a membrane. The membrane has to have certain properties, such as keeping mitochondria in and keeping unwanted toxins and foreign substances out. But it also has to have an opening or a way of letting in molecules that are desirable.

> Often, the inside of the cell has a slightly different electrical charge compared with the outside. In most cells, the inside contains more ions, or negatively charged molecules, than what's floating around outside the cell. This condition means that there is an electric potential across the cell membrane: Electrostatic forces are present such that positively charged things want to enter into the cell and negatively charged things want to leave the cell to bring equilibrium to the membrane.

MYTH

Your brain is perfectly designed.

TRUTH

A product of evolution, the brain is shaped by natural selection and includes many inefficient hacks.

> All living cells have different concentrations of ions inside them compared with what's just outside. But neurons and some other cells have harnessed this difference for some end goal. In the case of neurons, the goal, ultimately, is to send a signal to a nearby cell.

> If you open up a hole in the membrane of any cell, the stuff inside the cell can fall out. In the case of neurons, things that are negative will leak out and things that are positive will leak in, causing the electrical potential across that part of the membrane to depolarize, or become less negative and more positive.

- This depolarization is at the heart of the way in which neurons talk to each other. Once the amount of depolarization crosses a certain threshold, it sets off a cascade of events in the cell that culminate with the sending of an action potential, or a tiny electrical signal, down the end of the axon.

- This signal then can either be transferred directly to another cell or it can cause another cascade of events that results in the release of neurotransmitters, the cell's signaling chemicals, into the space between one neuron and the next.

- So, we can begin to see how any cell with a polarized membrane could eventually, over the course of many years and many incremental changes, turn into a fully functional neuron. Then, once we have one kind of neuron, the others just represent different personality types.

- You might be willing to accept that this type of evolution explains how neurons came about but still have trouble seeing how little hacks could lead to the emergence of all the complexity of the human brain.

EXPERIENCE

- To understand how this might happen on a slightly larger scale, consider how self-awareness and identity develop in children. They're not born with the same self-consciousness that ultimately plagues their teenage years. And the process takes time and experience with the environment, not just some biological process in a vacuum.

- A baby is not conscious of itself or of its thoughts and feelings and the world around it the way that an adult or even a child is. Most of the changes that happen during childhood that differentiate a 1-year-old from an 18-year-old are in the connections between neurons, not in their numbers.

Most of the changes that happen during childhood that differentiate a 1-year-old from an 18-year-old are in the connections between neurons, not in their numbers.

> One of the signs of healthy brain development in childhood is the pruning, or death, of neurons that aren't finding the right connections. A neuron whose messages are sent into the void, or one that isn't receiving sufficient signals, commits suicide. By the time a brain is fully developed, there are no neurons that aren't part of some network—because an isolated neuron dies.

> But from the perspective of a baby neuron, destiny seems quite random. What dictates whether a particular neuron will end up as part of the visual system at the back of the brain, or the central executive in the prefrontal cortex, or the emotional salience network in the middle of the brain? The answer is in a combination of chemical signals and the scaffolding that the network of helper cells, called glia, builds.

> Neurons are not the only cells in the brain. In fact, there are about as many support cells in the brain as there are neurons, if not more. This is another difference between the brain and most other

organs. Many of the cells in our body are much more self-sufficient when compared with neurons, which are like celebrities, needing an entourage of assistants to help them with basic functions. But their talent is in signaling and ultimately producing thoughts, feelings, and other exceptional skills that our brains possess.

> All cells start off the same—as daughters of stem cells—and initially, as the brain grows, changes are rapid and seem to be almost left to chance. This might be true, or it might be that we don't know what factors cause one progenitor cell to become a neuron and another to become a support cell.

> But eventually, the rate of change slows and neurons find their places by sending out signals to their neighbors and figuring out who is willing to talk. Those whose messages are not returned die.

> That's the micro level. At the macro level, when we're thinking about how the connections across the brain get formed, this process is magnified, but you can still see how complex cognition emerges from simpler processes.

> Brains develop and wire up with experience, and that's another way that diversity happens between different people and different brain regions. But this only happens gradually.

> Far from being perfectly designed, the wiring in our brains is actually highly contingent on environment and experience—and even on how our brains were used, stimulated, and developed in the past.

NOISE

> In addition to being shaped by evolutionary tweaks and personal life experiences, another factor that makes our brains far from perfect is noise, or randomness—for example, the random firing of action potentials.

- Neurons have a baseline firing rate. They send out random signals that don't actually carry meaning—at least, no meaning that we've been able to discover so far. And most of the energy used by the brain goes toward maintaining the electric potential across the cell membrane so that this firing is possible.

- We think of the action potential as the result of a summation of incoming signals from other cells. But the truth is that action potentials are randomly fired off all the time. And the signal, then—the meaningful message—is a change from this baseline firing.

- So, a huge amount of energy goes into this constant baseline firing, but the firing itself doesn't necessarily mean anything. It's only a change that carries meaning.

- Most of the energy the brain consumes sustains an essentially random and meaningless activity. Yet this randomness is also the base material that gets molded into a mind: both by Mother Nature, tinkering over millions of years, and by our own experiences over the course of a lifetime.

SUGGESTED READING

Dawkins, *The Blind Watchmaker*.
Faisal, Selen, and Wolpert, "Noise in the Nervous System."

QUESTIONS TO CONSIDER

1. What makes us so prone to latch on to brain myths?

2. What dangers are there in harboring such misinformation?

3. What are the unique challenges of thinking about thinking, as opposed to thinking about anything else?

2

ARE BIGGER BRAINS SMARTER?

Intelligence remains difficult to measure and next to impossible to define. Yet many people intuitively believe that people with bigger brains are smarter. There is a moderate correlation between human brain size and many measures of intelligence: The bigger a person's brain, the better he or she will perform, on average, on IQ tests. But this correlation is only moderate, and there are many other factors to consider.

BRAIN SIZE AND INTELLIGENCE

> Compared with many other species, humans are born with fairly small brains, leaving infants pretty much defenseless and unable to survive without a lot of care and attention at least for the first year. Wouldn't it make more sense, from the perspective of our chances of surviving long enough to reproduce, if we were born with more developed brains, making us at least capable of feeding ourselves, if not avoiding being eaten?

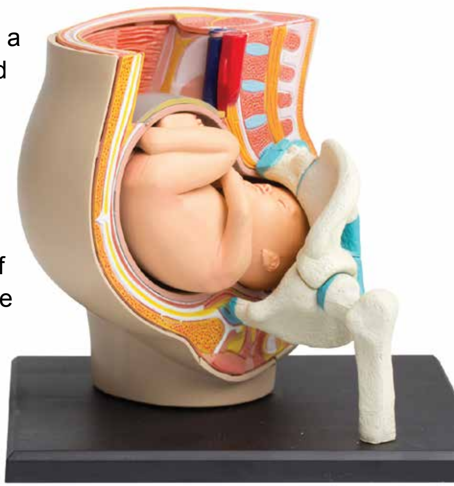
> To explain this conundrum, many people point to what's the obstetrical dilemma—the problem that walking upright supposedly created. A long-held idea is that during our evolution, there was a selection pressure for a smaller pelvis, to help us walk upright, which was then at odds with the selection pressure to house a bigger brain in newborns, whose heads have to pass through a woman's pelvis. The smaller the pelvis, the better able we are to walk, but the smaller the opening for a baby's head.

> This dilemma is used to explain why human babies are born rather underdeveloped. This explanation also purports to tell us why brain size triples in the first year and why the skull of a newborn has soft spots and cracks in it, enabling it to fold and squeeze through a small birth canal without damaging the brain encased within it—but leaves the baby vulnerable to grave injury until the skull closes and toughens up.

> New research is calling this view into question. Compared to other primates, our babies aren't really born prematurely. Other primate infants are also pretty dependent on their parents for a while after birth.

> And there's no evidence that a larger pelvis in women would interfere with walking or any of the other things we use our pelvis for. So, if it really was just about bigger brains, mothers would just develop wider hips. But the story of brain development is much more complicated than that.

> Instead, evidence is mounting that our gestation time is limited by the amount of food that a mother can supply to herself and her baby, and around the 40-week mark, this limit is reached. She simply can't get enough energy from food to fuel a growing baby and herself.



The smaller a woman's pelvis, the better she is able to walk, but the smaller the opening is for a baby's head.

> If you stand behind the argument that a bigger brain means more intelligence, then you're going to have to concede the prize for most intelligent animals to whales, with elephants not far behind.

If we quantify this as the ratio of brain size to body size, then humans clock in at about 1:40—the same ratio as a mouse.

- A number that might, in fact, matter is the encephalization quotient, which is the ratio of the actual brain mass over the expected brain mass of an organism with the same body mass. This ratio takes into account the fact that bigger bodies are expected to house bigger brains. But our brains are quite a bit bigger than the brains of the other mammals who are about the same size. The lowly mouse looks fairly stupid and humans do come out on top, beating dolphins, whales, and elephants by a fair margin.

MEASURING INTELLIGENCE

- Consider the notion that there exists some kind of measurable general intelligence. Figuring out what it is and whether and how it can be developed or enhanced is a billion-dollar question that psychologists have been trying to answer for decades.

- The *g* ("general") factor is what many psychologists have spent entire careers searching for. The idea is that there is a common factor that correlates with performance on a wide array of tests of cognitive abilities: If someone is very good at math, he or she is also likely to do well on other tests of intelligence, such as vocabulary and reading comprehension. And there's a fair amount of evidence supporting this idea.

- Most studies show that the *g* factor accounts for about 40–50% of the variability between subjects on IQ tests. And it seems that *g* is highly heritable. It can predict with fairly decent accuracy how well a child will do in

> MYTH
>
> The bigger the brain, the better.
>
> TRUTH
>
> Intelligence and brain size, even in humans, are only moderately correlated. When you look across species, the correlation is even smaller.

school and how far they will get in their careers. And it correlates with total brain volume, though only moderately so.

> That means that a significant portion of the variability in this general intelligence factor has nothing to do with the size of your brain. Height is also associated with *g*, so taller people might be smarter, on average, given their bigger brains.

> Once the *g* factor was suggested and fairly widely accepted, it was further divided into 2 types: fluid intelligence and crystallized intelligence. You can think of them as the difference between quick thinking and wisdom. Fluid intelligence peaks in your 20s, while crystallized intelligence remains steady, or steadily increases, throughout adulthood, depending on how you use your brain.

> But despite the evidence for the existence of a *g* factor, whether fluid or crystallized, not all psychologists are happy with the notion that there is one major underlying ability. Perhaps the most famous challenge to *g* is Howard Gardner's multiple intelligences theory, which considers the soft skills, such as social graces, that might not be captured on traditional IQ tests.

> In his theory, Gardner suggests that there is no single factor, but that intelligence comes in many kinds, including musical intelligence, visuospatial, verbal-linguistic, logical-mathematical, bodily-kinesthetic, and so on.

> Gardner's theory caught on quickly, but despite the intuitive attractiveness of the idea, the evidence supporting his theory is slim to nonexistent.

EINSTEIN'S BRAIN

> Luckily for science, Albert Einstein's brain was saved for postmortem analysis. At least in 4 different sections of his brain, and at least compared with a certain cohort of war veterans, the ratio of neurons (generally thought to be the content of the brain)

to glial cells (which provide the neurons with the basic necessities of life and ensure that they can concentrate on firing off, or not, a signal) was found to be lower in Einstein's brain than in his veteran counterparts.

> However, this ratio difference was only significant in 1 of the 4 brain sections studied, and the researchers conducting the analysis knew which slices belonged to Einstein and which belonged to the vets, so maybe they were unconsciously influenced to find differences. In addition, there's a paper in which the lower neuron/glia ratio in the left parietal region is used as an explanation for Einstein's purported dyslexia.

> Furthermore, research on a section from Einstein's prefrontal cortex, which is responsible for complex cognition, shows that his cortex was thinner than that of controls but that the neurons there were more densely packed. In many studies, cortical thickness is taken to be a good thing, and aging and neurodegenerative diseases can cause cortical thinning.

> Maybe more densely packed neurons gave Einstein an intellectual edge: Perhaps neurons that are close together can communicate more quickly and efficiently with each other. However, people with schizophrenia have also been shown to have more densely packed neurons in the prefrontal cortex.

COMPOSITION OF BRAIN REGIONS

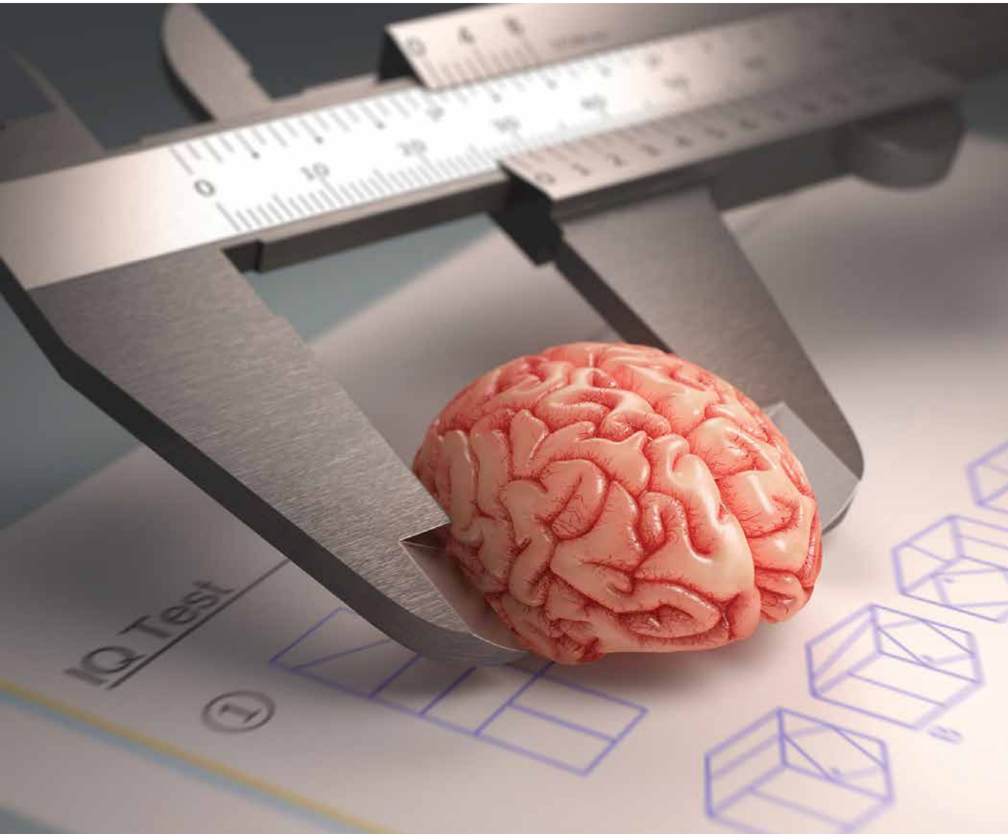
> If overall size is not the answer, perhaps it's the composition of specific brain regions—those that are important for the types of thinking that IQ tests measure. And there are plenty of studies that have found correlations between different aspects of neuroanatomy and IQ test performance.

> Broadly, these studies can be divided into 2 types: those that measure differences in gray matter (roughly translating into the

number of neurons) and those that look for differences in white matter, or the connections between neurons.

- Gray matter in the frontal lobes does correlate with intelligence, as measured by IQ tests, at least. For example, spatial tasks and verbal tasks are thought to rely heavily on the *g* factor, and they seem to activate or rely on a set of regions in the front of the brain. Apparently, the more gray matter that is in these regions, the better the performance is on these particular tasks.

- And there’s evidence from patients with brain damage or deterioration of gray matter in the frontal cortex that demonstrates how important this region is when it comes to behaving intelligently: Patients with damage to the region tend to show



worse performance on intelligence tests and make bad decisions in daily life.

> So, maybe size does matter when it comes to the frontal lobes, though the story is quite complicated. It gets even more murky when we start to consider that the frontal cortex doesn't act in a vacuum and that the real work of the brain happens between neurons, not within them. This is where white matter comes in.

> White matter represents the connections between neurons. How much white matter you have might be an indicator of how well and how quickly your neurons can communicate with each other. Scientists who study the relationship between white matter and intelligence say that they are investigating the neural correlates of quick thinking. The idea is that a person with more white matter does, in fact, think more quickly than someone with impoverished connectivity. And the faster speed of thinking then translates to greater intelligence.

> Indeed, we can find correlations between the amount of white matter a person has and how he or she scores on intelligence tests. The corpus callosum, which is the largest tract of white matter in the brain, connects the left and right hemispheres. And a larger callosum correlates with better performance on a range of cognitive tests, though not all measures of callosal volume have shown statistically significant effects.

> Some neuroscientists take this mixed evidence as suggestive of the idea that gray matter may be more important when it comes to defining the neural basis of intelligence.

OUR SPECIAL BRAINS

> Brazilian neuroscientist Suzana Herculano-Houzel devised a way of counting the cells in the brain that has called into question the very idea that our brains are special. In fact, she argues that the endurance of the encephalization quotient might have more to do

with confirmation bias than with any real evidence because it's the one measure of intelligence that makes our species an outlier.

> It might not be that we have bigger brains compared with our primate cousins, but that they have bigger bodies than we do; that is, maybe we didn't evolve bigger brains but our primate cousins evolved bigger bodies and their brains stayed the same size or even became smaller.

> We don't have the biggest brains in the animal kingdom. And Suzana Herculano-Houzel has shown that larger brains don't even necessarily mean more neurons. A primate brain that is the same size as a rodent brain will contain many more neurons.

> Herculano-Houzel devised a model that predicts how many neurons and support cells a primate brain of a certain size should contain. Her model predicts that if we were just the logical next step on the evolutionary path, our brains should contain about 93 billion neurons and about 112 billion glial, or support, cells. The average human brain has about 86 billion neurons and 85 billion nonneuronal cells.

> Our primate cousins, the great apes, have smaller brains than their body size would predict because neurons are expensive from an energy-use perspective. And gorillas and chimpanzees simply can't get enough fuel from their food to power more brain cells than they have. Once again, food might explain why babies are born with small brains.

> Perhaps the reason we can handle our big brains is because we figured out how to cook. Cooking our food freed up time to do all the other things that ultimately have shaped our brains into the sophisticated thinking machines that they are today.

> Herculano-Houzel's work puts the nail in the coffin of the idea that brain size or the encephalization quotient matters. But her work does help us answer the question of what makes us special. Now

that we can get all the calories we need from cooked food, we can spend time shaping our average primate brains into powerful thinking machines.

> But Herculano-Houzel cautions against applying this method to predict the number of neurons individuals in a species might possess. Her work has shown that intraspecies variability in the density of neurons is considerable and doesn't correlate strongly with brain size.

SUGGESTED READING

Chudler, "Brain Facts and Figures."
Herculano-Houzel, "The Human Brain in Numbers."
Hines, "Neuromythology of Einstein's Brain."
Plomin and Spinath, "Intelligence."
Toga, Wright, and Thompson, "Genetics of White Matter Development."

QUESTIONS TO CONSIDER

1. What advantages might a bigger brain afford?

2. If it's not size that differentiates us in terms of intelligence or other factors, what might the physical signature of genius be? Or is there one?

3

IS MENTAL ILLNESS JUST A CHEMICAL IMBALANCE?

The notion that the major psychiatric illnesses stem from too much or too little of one neurotransmitter can trace its roots to a time when doctors observed profound effects on a person's psychiatric well-being with the administration of a single drug. The effects of the drug suggested that there was a fairly straightforward relationship between mental illness and neurochemistry. But mental illness is complicated.

CHEMICALS IN THE BRAIN

- There is one major difference between the way that chemicals enter the brain and how they roam around the rest of the body. Your body has a built-in protection system: When foreigners invade, your body unleashes an immune response to fight them off.

- The immune system works in a number of ways, but one crude defense mechanism is to kill infected cells. But if a bacterial colony infected your brain cells and the immune system's response was to kill them off, you'd have a big problem.

- Instead, we've evolved what's known as the blood-brain barrier—a physical barrier between the blood circulating in the rest of our bodies and our brain. Endothelial cells line the capillaries in the brain, preventing most compounds from moving between the blood and the cells of the brain. Molecules such as oxygen and

hormones are small enough to pass through, but most bacteria, viruses, and toxins are kept out.

- This barrier ensures that bacterial infections of the brain are very rare. But it also poses a problem for drug companies that want to alter the balance of chemicals in your brain. You can't just ingest a pill and expect that compound to make its way into the brain. Getting past the blood-brain barrier is a major challenge for pharmaceutical companies.

- Caffeine gets through because it's so similar to adenosine, which is found throughout the nervous system. Alcohol passes through, too, because of its electrochemical properties. And, luckily, many antidepressants and other psychiatric medications contain compounds that are small enough to get through—but not all of them.

> MYTH
>
> When the chemicals in your brain are out of balance, your brain can't function properly.
>
> TRUTH
>
> Neurotransmitters, the chemicals in the brain, are only one part of healthy brain function, and their levels are in constant flux.

- Along the blood-brain barrier, there are specialized gates that let in specific larger compounds that are useful to the brain. Still, most pharmaceutical compounds simply get left out.

- Once a compound does make it through, it then needs to actually affect the functioning of the brain. Neuroscientists have focused on how neurotransmitters, or the chemicals that are involved in signaling between neurons, work.

- Dendrites are the parts of neurons that receive information, while axons are the projections that pass on the signal. Both axons and dendrites contain gates along their membranes that selectively allow certain compounds to pass through.

> Along the dendrites, these gates are called receptors because they are receptive to specific neurotransmitters. Neurotransmitters can affect receptors in different ways. But one common effect is to cause the receptor to open a gate that changes the proportion of negative and positive ions inside the neuron.

> The inside of the cell is slightly more negative than the outside, so positive ions outside the cell are hankering to come into the cell. When the gates open, they can do so. This influx causes the inside of the cell to become less negative, or slightly more positive. And if enough gates are opened, the inside of the cell becomes positive enough to pass a threshold and set off an action potential down its own axon, which causes it to release neurotransmitters all along the complex circuitry of the brain.

> Some neurotransmitters actually block gates, making it less likely that the neuron will send an action potential. And neurotransmitters often bind to different types of receptors.

SCHIZOPHRENIA

> The term "schizophrenia" is often misinterpreted to mean split personality. When someone does something out of character, his or her behavior is sometimes described as schizophrenic. Not only is this use of the word offensive to individuals who suffer from the disease, but it's also simply incorrect.

> Schizophrenia was originally coined to describe the disordered thinking that can accompany the disease—split mind, not split personality. Schizophrenia describes a disease that is extremely heterogeneous: 2 patients with the same diagnosis can present with very different symptom profiles.

> One patient might suffer primarily from positive symptoms—an increase in the frequency or magnitude of certain behaviors, such as delusions and disordered thinking. Another patient, with the same diagnosis, might show mainly negative symptoms—

an absence or drop in frequency of certain behaviors, such as catatonia or flat affect.

- The patient with positive symptoms will look, superficially, very different from the patient with negative symptoms. Yet these 2 manifestations of the disease have some underlying things in common.

- Schizophrenia runs in families, and the same genes can be expressed in one carrier as mainly positive symptoms and in another as mainly negative. In addition, the same patient can show more positive symptoms during one episode and more negative ones during another.

- But the relative frequency of symptoms is also an indicator of how much help drugs can be for a particular patient. That's because

the serendipitous discovery of the drugs that are largely used to treat patients with schizophrenia was related to the treatment of positive symptoms: hallucinations, delusions, and some aspects of disordered thinking.

> The discovery of antipsychotic medication revolutionized the treatment of people with schizophrenia, shifting away from long-term institutionalization and toward a combination of psychotherapy, social work, and medications.

> Because antipsychotic medications can have such a dramatic effect on the positive symptoms of schizophrenia, neuroscientists proposed a theory of the disease based on how they understood the mechanism of action of these drugs.

> Most antipsychotic medications bind to dopamine receptors, blocking them from the dopamine that the brain produces. So, the dopamine hypothesis of schizophrenia suggests that the disease results from too much activation of a specific set of dopamine receptors called D2.

> Because dopamine receptors are found all over your brain, and different circuits of your brain have different functions, the dopamine hypothesis suggests that positive symptoms are a result of too much dopamine in one pathway or circuit and negative symptoms are caused by too much of it in a different pathway.

> It's possible that even the distribution of these receptors across the brain is different in individuals with schizophrenia, explaining one of the ways in which the genetic factors might be operating—or the way the genes are expressed, because trauma and hormonal shifts in adolescence might also make a person more likely to develop the disease.

> So, it's not just about the amount of neurotransmitter in the brain that causes symptoms. How many receptors there are also makes

a difference, and receptors can be built or lost through gene expression, hormonal signals, or traumatic experiences.

> But notice that proponents of the chemical imbalance myth are in trouble here: Combatting schizophrenia is not as simple as depleting the brain of dopamine. Where the dopamine is excessively activating a certain type of receptor matters. And drugs that block dopamine receptors have not been very successful in alleviating negative symptoms.

> Even so, the dopamine hypothesis has other data in favor of it—data that seem to bolster the evidence drawn from the treatment of the positive symptoms of schizophrenia. For example, drugs that mimic dopamine, when taken in excess, particularly over long periods of time, can cause psychosis, or symptoms that resemble those found in patients with schizophrenia.

> Considering this evidence, the idea that schizophrenia is caused by too much dopamine sounds compelling. But not only is the dopamine hypothesis more nuanced than just a proposal that there is an imbalance of one type of neurotransmitter, there is also emerging evidence that dopamine might not even be the main player.

> For one thing, many patients don't respond well to drugs that block D2 receptors. Another line of evidence comes from atypical antipsychotic medications. These are newer drugs that cause fewer side effects. They're more effective than the typical antipsychotics in treating the negative symptoms of schizophrenia but just as effective at diminishing the positive symptoms. They have been found to be less efficient at blocking D2 receptors, and they also affect serotonin, another neurotransmitter.

> Glutamate, the most common excitatory neurotransmitter in the brain, has also been implicated in schizophrenia. Drugs that block glutamate receptors can also induce schizophrenia-like symptoms. Nicotine increases levels of glutamate in the prefrontal cortex and

is commonly abused by patients with schizophrenia, who report that it helps them focus.

> Scientists studying people with schizophrenia have put forth a glutamate hypothesis of the disease: that glutamate keeps dopamine in check, and without enough glutamate, dopamine has a larger influence on brain function than in a healthy person, and symptoms of schizophrenia might be the result.

> But drugs that increase glutamate levels in patients with schizophrenia have not been very successful at reducing positive symptoms.

> And, to complicate matters further, neurotransmitter levels aren't the only ways in which the brains of people with schizophrenia are different from those of comparatively healthy people. Volumes of brain matter in certain regions, such as the frontal cortex and the temporal lobes, are smaller in many people with schizophrenia.

> Functional differences—that is, the way in which certain tasks activate the brain—have also been found in regions such as the frontal and temporal lobes and the hippocampus. And the connections between regions also seem to be different in patients versus controls.

> It's not clear whether these neuroanatomical and functional changes are a cause or an effect of the disease or even the medications themselves. And we don't yet know what is causing the changes in neurotransmitter efficacy.

DEPRESSION

> The chemical imbalance myth is also tossed around liberally with depression. The chemical imbalance theory of depression has its roots in the serendipitous discovery of tricyclic antidepressants such as imipramine.

- We now know that tricyclic antidepressants work on a class of neurotransmitters called monoamines—dopamine, serotonin and norepinephrine are all affected by the drugs.

- Around the time that imipramine's antidepressant properties were being touted, a group of physicians published their finding that a drug designed to treat tuberculosis seemed to produce euphoria in some patients. This drug also worked on monoamines, inhibiting the enzyme that breaks them down, known as monoamine oxidase. As less of a neurotransmitter is broken down, more of it is available for use by neurons. So, administering a monoamine oxidase inhibitor leads to more norepinephrine and serotonin floating around in the brain.

- Many antidepressant drugs act on norepinephrine, dopamine, and serotonin. But each neurotransmitter is involved in a different set of brain functions. Norepinephrine modulates attentional focus

and general arousal levels. Dopamine is involved in feelings of pleasure, motivation, and working memory. Serotonin can decrease anxiety, obsessive rumination, and compulsions.

> Every one of these functions is implicated in people with depression, to different degrees. So, psychiatrists are counseled to create a recipe of drugs that matches the symptom profile of a specific patient.

> If depression were just a chemical imbalance, you'd think that symptom abatement would happen as soon as the chemistry is reset. But with antidepressant drugs, there's a therapeutic lag: The neurotransmitter levels are altered almost immediately, but it takes weeks for patients to feel better. The reason why is a big conundrum, but it means that it's not just about restoring chemical balance.

> What's more, patients with depression don't have low levels of monoamines. Many patients, even with major depression, have the same levels of neurotransmitters in their cerebrospinal fluid as their healthy counterparts. And lowering levels of monoamines in healthy people doesn't lead to depression.

> And some patients experience symptom relief from antidepressants that don't even act on monoamines, at least not directly. And cognitive behavioral therapy, during which patients work with a therapist to change thought patterns and reactions to negative situations can be just as effective as drug treatments for people with mild or moderate depression, even showing similar neuroanatomical and physiological changes.

> Perhaps putting the nail in the coffin of the chemical imbalance story of depression, many patients with mild to moderate depression show as much improvement when taking a placebo as they do with pharmacologically active drugs.

- Just like in patients with schizophrenia, there's a long list of other physical differences in the brains of people with depression. Even the way the brain changes in response to experience—called neuroplasticity—is different in some patients.

- A new approach to treating mental illnesses is the use of genetic information to tailor drugs to the patient. But we should also consider the psychological treatment options. Finding other noninvasive ways to rewire and reshape the brain with therapy is another promising future direction.

SUGGESTED READING

Ban, "The Role of Serendipity in Drug Discovery."
Barton, Esler, Dawood, and Lambert, et al, "Elevated Brain Serotonin Turnover in Patients with Depression."
DeWall, Gillath, Pressman, and Black, "When the Love Hormone Leads to Violence."
Lacasse and Leo, "Serotonin and Depression."

QUESTIONS TO CONSIDER

1. How do brain chemicals, neurotransmitters, and hormones enhance the ways that neurons can communicate with one another?

2. How can one neurotransmitter, such as dopamine, have such different functions, from enabling working memory to giving us the experience of pleasure?

4

ARE CREATIVE PEOPLE RIGHT-BRAINED?

For many people, the idea that a person can be proficient in both art, reserved for right-brain-dominant people, and science, where the left brain steers the ship, seems nearly impossible. Is there any truth to the idea that we have a dominant hemisphere and that left-dominant people are less creative, or more logical, than right-dominant ones? Does tapping into your right hemisphere make you more creative?

RIGHT VERSUS LEFT

> An idea that has been overused and misinterpreted by many people is the notion that the left side of your brain is logical and analytical while your right side is creative—and instead of working together, these 2 hemispheres are in competition with one another. And if you can tap into your right brain, releasing it from dominance by the left, you can be more creative, or that you need to shut down your overbearing left hemisphere to do something original and artistic.

> There is evidence that patients with specific lesions to one side of the brain may show a different symptom profile from patients with comparable lesions to the other side. The brain is to some extent modular, in that different brain regions are assigned different roles. But the truth is much more complex.

- Studying groups of lesion patients helped neuroscientists discover that certain cognitive functions, such as language, are localized primarily to one side. This assignment of different functions to the 2 different hemispheres is known as lateralization.

- When it comes to our senses and actions, in particular, the 2 sides of the brain process different sets of information. The left side of space is represented primarily in the right hemisphere, and vice versa.

- This means that your right hand is controlled by the left side of your brain, and what you see in your left visual field is projected to the back of the right side of your cerebral cortex. The assumption is that if you engage the left side of your body, you'll tap into your creative right brain. But there are a few assumptions that such an explanation glosses over, most of which aren't true.

- Just as you have a dominant hand, most likely you also have a dominant hemisphere. Actually, because you have a dominant hemisphere, you also have a dominant hand. Neuroscientists are still working out the details of how related the lateralization of cognition and handedness really might be—and how they develop—and the story is getting more complicated by the day.

- For people who are right-handed, the left hemisphere is the dominant hemisphere, and the left side of the brain contains most of the language function. But if you're left-handed, then there's only about a 20% chance that your right hemisphere is your dominant hemisphere. And there's also a 20% chance that both of your hemispheres contain language function. As for the rest of the lefties, they've still got about a 50–60% chance that most of their language function is on the left side.

- And even though many language functions rely on an intact left hemisphere, the right hemisphere certainly participates in verbal communication. The right side is much better at deciphering prosody and accentuation, while the left is the home of the grammar police and the dictionary.

> Before the explosion of neuroimaging research, studying patients with lateralized lesions or commissurotomies was the best way to figure out what the 2 sides of the brain might be doing. But tracking activity in the brains of healthy people while they are engaging in different tasks, as we do with neuroimaging, provides another, perhaps more modern window into laterality.

- For example, neuroimaging studies suggest that the 2 hemispheres might play different roles in emotion processing, with the left hemisphere showing somewhat greater activation for positive emotions and the right hemisphere showing more activity during negative emotional processing.

- An insight that neuroimaging has offered is that white matter tracts, or the wiring diagram, of the 2 hemispheres is different. The wiring of the right hemisphere has been called more efficient because it has greater connectivity between regions. The left hemisphere, in contrast, seems to be more modular.

- This wiring difference might explain why the left hemisphere seems to contain regions that operate somewhat more independently and are more specialized than the regions in the right hemisphere, which are involved in more integrative processes, such as visuospatial tasks.

- It's easier to find specialization in the left than the right hemisphere. And here, too, people looking for evidence for the association between the right brain and creativity and the left brain and logic point to these wiring differences.

- Neuroimaging research has also shown just how communicative the 2 hemispheres are: Unless that connection between them is severed, information is zipping across the hemispheres during the vast majority of tasks that we ask our brains to accomplish.

- And in many regions, signals pass from one hemisphere to the other more quickly than they do within a single hemisphere; that is, some signals from the left and right prefrontal cortex can be exchanged more efficiently than signals from the back of the brain to the front of the brain in the same hemisphere.

STUDYING PATIENTS WITH SEIZURES

- To understand what underlies the left/right brain myth, why it's wrong, and how much more interesting the truth is, we need to

go back to a time before neuroimaging—with the psychologists who were among the first to suggest that the 2 hemispheres of the brain might play different roles.

> In the 1940s, 2 neurosurgeons attempted an experimental procedure to help curb seizures in patients with severe cases of epilepsy. Seizures are caused by the spread of abnormal electrical activity in the brain. Usually, this activity starts in one part of the brain and spreads across the brain, following the trajectory of neural pathways. When this electrical activity is severe enough and widespread, people with epilepsy experience dangerous and debilitating seizures.

> In the 1940s, neurosurgeons reasoned that if they could contain the electrical misfiring to only one side of the brain, the seizures wouldn't be as severe. They proposed a surgical procedure that would sever the corpus callosum, the information superhighway that connects the 2 cerebral hemispheres of the brain. By cutting this fiber tract, they believed they could trap the abnormal electrical activity in one hemisphere.

> Unfortunately, these initial surgeries had no positive effect on their patients, and the technique was quickly abandoned—until the early 1960s. That's when other neurosurgeons working with seizure patients realized that the idea of severing the connections between the 2 hemispheres of the brain was actually sound. The problem with the initial experiments was that the technique was flawed.

> In the first surgeries, only the corpus callosum was cut. But there are actually 2 other routes through which abnormal neuronal activity can transfer from one side of the brain to the other. These are the hippocampal and anterior commissures.

> The neurosurgeons performed new surgeries that severed these additional routes along with the corpus callosum. The neurosurgeons called these new operations commissurotomies, and they found that these procedures successfully curbed the spread of seizures in a number of severely epileptic patients. Their

success came from being able to fully sever the communication between the 2 halves of the brain.

> We don't do this surgery very often anymore, because the drugs available for curbing epilepsy are much better than they were in the 1960s, and less invasive surgical procedures have since been developed.

COMMISSUROTOMIES

> Around the same time, a neuropsychologist named Roger Sperry, together with his student Michael Gazzaniga, began testing these so-called split-brain patients to find out what aspects of the human mind are processed in each hemisphere of the brain. This pioneering work seeded the left/logical, right/creative brain myth.

> Once neurosurgeons began performing commissurotomies, they started producing patients with left and right hemispheres that could no longer exchange information. This means that what their left brain knows, their right brain might not, and vice versa. Realizing this was the case, Sperry, Gazzaniga, and other investigators began devising novel ways to query one half of the brain at a time.

> For example, using the fact that what is in our left visual field is only seen by the right hemisphere, they would show the right hemisphere a series of images very briefly. And then they would ask the patient to respond in some way.

> The tricky thing about split-brain patients is that they compensate for the fact that their 2 hemispheres operate independently by moving their heads so that anything they see or hear enters both sides of the brain.

> To be able to talk to one hemisphere without the other interfering, psychologists studying the patients devised a clever apparatus that limits the information that each hemisphere receives. They

could, for example, have the patient looking straight ahead and then flash a word to the left or the right and thereby control which hemisphere "sees" the word.

> Every time you talk with someone, you're relying on the left hemisphere of your brain to keep up with and make sense of the exchange. So, when the split-brain patients were asked what they saw with their right hemisphere, often they would simply say "I don't know" or "nothing," because the talkative left hemisphere didn't have access to what the right hemisphere was seeing.

> But then if they were asked to choose from a set of alternatives—for example, by pointing to a picture of something that's associated with the thing that their right brain saw—they would be completely surprised when their left hand instinctively reached out and made a choice or responded to a command. In fact, they often felt as though they were just guessing.

> And when the patient was asked why he or she performed that particular action, the left brain—which dominates speech—spontaneously made up a story to explain the behavior.

> Gazzaniga was the first to suggest that in between these patients' actions and their responses, there's a part of their brains that interprets what they're doing. He called this storytelling function of the brain the interpreter, and he localized it to the left hemisphere, along with language.

> Another term for this type of interpretation, this justification of an action without enough information to know why it was done, is confabulation.

> Gazzaniga found that confabulation in split-brain patients occurred when the left-sided interpreter was forced to justify an action without information from the right hemisphere of the brain for why it happened. This means that when the left brain did not know what the right brain was doing, it simply made up a story after the fact

to explain the decision. And it was a story that the patient really believed to be true.

> These instances of confabulation in patients with commissurotomies offer pretty fascinating insights into how our own brains function. And by querying one hemisphere or the other independently, these patients have provided us lots of information about what types of cognitive processes and information are localized in each of the 2 hemispheres, in most people.

> But the most striking thing about split-brain patients is that it's really difficult to tell, from interacting with them, that there is anything amiss. Both sides of the brain spend much more time working together and sharing information than operating independently in the healthy brain. They work together and are both necessary for complex thought.

> The idea that the brain is strictly modular—that different brain regions have different functions—is no longer accepted in neuroscience. Instead, we talk about networks or circuits of regions that work together. And many of the circuits cross the line between the 2 hemispheres.

MYTH

Logical people are left-brained and creatives are right-brained.

TRUTH

The hemispheres are highly interconnected and work together in sync much of the time. Although there is some lateralization of function, many functions are bilateral, and the left brain is necessary for creativity.

HEMISPHERECTOMIES

> Patients who have had half of their brains surgically removed demonstrate just how malleable lateralization can be. Removing half a brain is called a hemispherectomy, and it's a last-resort treatment

for patients with a damaged hemisphere that is threatening or harming the rest of the brain.

> Hemispherectomies are rare. They're usually performed on children whose brains have a better chance of recovering function than those of adults, and it's well established that lateralized functions in the healthy brain, such as language, can be rewired into the other hemisphere, especially if the patient is very young.

> This rewiring demonstrates one of the amazing super powers of the brain—the ability to repurpose cortical real estate for important functions when the regions that are supposed to carry them out are damaged. This plasticity is seen both before a child develops the activity and even after the function has begun to develop. Remarkably, these patients can go on to lead impressively normal lives.

SUGGESTED READING

Turk, Heatherton, Macrae, Kelley, and Gazzaniga, "Out of Contact, out of Mind."
Wolman, "The Split Brain."

QUESTIONS TO CONSIDER

1. Why would it be helpful to have some functions localized in one hemisphere or the other?

2. In a healthy person, whose corpus callosum (the fiber tract that joins the 2 hemispheres) is intact, is there more communication between the hemispheres than within them? What does that mean in terms of how we understand lateralization?

3. How is it possible that a person can be born with only one hemisphere and not know it?

5

HOW DIFFERENT ARE MALE AND FEMALE BRAINS?

There are biological differences between the brains of men and women. After all, sex hormones dictate some of our neural development even in the womb and affect brain function even in adulthood. And natural selection is not the only force determining evolution; sexual selection has guided us all along the way, too. But it's easy to tell "just-so" stories when it comes to understanding how sexual selection plays a role in evolution—and that temptation is best avoided. What are the popular myths that neuroscientists studying the differences between the brains of men and women have to fight?

MEN VERSUS WOMEN

> It is a popular myth that men are smarter than women simply because, on average, men have bigger brains. The relationship between brain size and intelligence is complicated, and bigger doesn't mean much when you compare individuals, because brains can be more or less densely packed, with faster or slower connections. In addition, many women have brains that are larger than those of most men.

> There are both morphological and functional differences in the brains of the average male and female, but there are also major differences between individuals of the same sex, and these differences often trump sex.

- Taking men as a large population and women as a large population, we can discern differences, on average. But to apply these differences to individuals is simply ill-informed. There is much more overlap in the distributions of traits in both populations than there is separation between them, and individual differences in brain size, morphology, and function are rampant.

- When we talk about average differences between the brains of men and women, we need to remember that any given individual you meet may fall almost anywhere along the continuum.

- In fact, a large-scale imaging study published in 2015 found that most brains contain both male and female traits. That's true whether the researchers were looking at the numbers of cells in different brain regions (gray matter), the amounts of nerve fibers (white matter), or the connections between different brain regions.

- Most brains are a mosaic of both genders, and it's difficult to call a brain male or female just by looking at these features. When the authors further checked datasets for stereotypically male or female behaviors, they also found that individuals were mixed, with only 0.1% of research subjects showing only stereotypically male or female behaviors.

- Yet we often hear about studies that find significant differences. How should we interpret these conflicting pieces of information? First, we need to agree on how to measure differences, and only then can we interpret their meaning.

MEASURING DIFFERENCES

- In biology, morphological differences between males and females of the same species are known as sexual dimorphisms. The difference between the peacock's and the peahen's tail is an obvious example.

> But when you scan neuroscientific data for sexual dimorphisms in human brains, you have to consider the variability in your sample. For example, a man and a woman who grew up in the same socioeconomic status, share the same culture, and are of the about the same age are going to show more similar performance on a set of cognitive tasks than 2 men with different educational backgrounds, ages, and cultures.

> The studies that show morphological differences have to have large sample sizes because there is massive variability in both overall and regional brain structure and function between individuals.

> Furthermore, age is arguably a greater predictor of brain differences than gender, for many variables. Sexual dimorphisms

change with age. Some differences attenuate; others are exacerbated. Also, brain function doesn't always correlate directly with brain morphology.

> When we talk about gender differences in the brain, we need to consider that the brain is a moving target. The very strength of this organ lies in its plasticity, which isn't infinite—it is limited by biology—but this variability adds an additional layer of complexity to the issue.

> Gender differences can be thought of as belonging to 3 categories.

1. The first category includes differences that are, by definition, always present and dimorphic between men and women. These are differences related directly to sexual reproduction and sex hormones, and they are found almost exclusively in one sex or the other.

2. The second category includes differences that fall along a continuum, and males and females have different distributions or averages along that spectrum.

3. The third category includes differences that change over time. Sometimes, men and women are more different on a particular trait at one time or under certain conditions but are more similar as conditions change or time passes—or they start off the same but diverge later in life or under different circumstances.

> While mischaracterizing the biological differences in the brains of men and women is not a good thing, there is a corollary of interpreting these data that is even more damaging: when we make the inference that sex differences in the structure or even function of the brain predict behavioral differences, which can then lead to discrimination and prejudice—all founded on a mythical idea that a person's gender can accurately predict brain differences and therefore behavior in a particular individual.

KEY DIFFERENCES

> There are several key differences in the brains of heterosexual men and women that are worth highlighting.

> Three regions in the brain that, on average, have been shown to be different in men and women, after correcting for body size, are the amygdala, an almond-shaped structure that plays a key role in the emotional modulation of memory; the hippocampus, whose job is to lay down new long-term memories and to navigate through space; and the corpus callosum, the fiber tract that joins the left and right hemispheres. But the story isn't quite as simple as we'd like it to be.

> The amygdala is generally larger in men than in women. The amygdala helps us remember details of events that were very emotional. The amygdala plays a role in telling the hippocampus to pay attention.

> Studies documenting behavioral differences in the recall of emotional events by men and women find that women seem to have stronger and more detailed memories of emotional events and are able to bring them to mind more quickly. So, the increase in memory strength that happens with emotion is bigger in women than in men, on average.

> This memory enhancement might sound like a benefit, but it might also be one of the reasons why women tend to be diagnosed more frequently with disorders such as depression, anxiety, and PTSD. There's some evidence that memory for things that happened just before an emotional event is worse in women than in men.

> There's also evidence that the amygdala has different functions in men and women when it comes to sexual behavior. the average male amygdala is larger than the average female amygdala, even when you account for total brain size. The amygdala is full of sex hormone receptors, so this biological difference can be attributable

to the brain changes that happen as a result of sex hormone activity. So, the amygdala develops differently in men and women, likely because of the different levels of sex hormones in the brain.

> There are also anatomical differences in a structure adjacent to the amygdala, the hippocampus. Several studies have found that women tend to have a larger hippocampus, on average, than men. That might be because the hippocampus tends to decline with age, starting when a man is in his 30s, but not in women, as described in a study from 2001. And stress can have different effects on the hippocampus in men and women, under different conditions.

> But a large meta-analysis, published in *NeuroImage* in 2015, found no differences in hippocampal volume between men and women. So, maybe the other studies that found differences simply didn't include enough participants.

MYTH

Men's and women's brains are structurally different.

TRUTH

The similarities between the brains of men and women far outweigh the differences, and the differences are difficult to tease apart from different environments.

> On average, women's brains have proportionally more gray matter than men's brains, and men's brains have a larger percentage of white matter, which connects neurons. When we consider the corpus callosum—which is the largest bundle of white matter in the brain—the connectivity story gets even more complicated.

> The corpus callosum is often cited as one of the regions that shows robust sexual dimorphisms. Studies have found that women tend to have larger and more bulbous corpora callosa than men, and this finding has been interpreted as showing that women have more communication between hemispheres and think more holistically. This difference was first reported in 1982.

- In 1991, a second paper came out indicating that it's more bulbous in women, but more tubular in men and the total area is the same. Then, a meta-analysis in 1997 found no significant sex differences across 49 studies of the corpus callosum. Finally, a study in 2003 showed that in Indian brains, the corpus callosum is longer in males than in females and that it increases with age in males but not in females.

- These studies show that measuring brain volumes, even in the same region, is complex and that variability with age, culture, and other factors muddies the waters significantly.

- Some of the differences in connectivity have also been used to promote the left/right brain myth: that because women are supposed to have greater interaction between the hemispheres, they have greater access to the nondominant, intuitive, and emotional right hemisphere, while men are more dominated by their logical, analytical left hemisphere.

MEDICAL RESEARCH

- There is a need for more research on sex differences in the brain, because these differences, when they are real, have direct implications for our health. There is a difference in prevalence, for example, for many psychiatric and neurological disorders between the sexes. And to properly treat men and women with these disorders, we need to understand the differences in their neurobiology.

- Men and women might react to the same conditions in different ways. They may then show biological changes that are not the same, and we need to understand these differences if we are to properly diagnose and treat diseases. Sex differences can show up in disease prevalence, prognosis, and/or response to treatment.

- Yet there is a very prevalent bias in medicine to focus on male patients and male animals. Among animal researchers, the argument has been that unless there's clear evidence of sex differences, male animals are easier to deal with than female animals because they don't have to worry about the estrus cycle. And the hormonal changes that accompany estrus do affect animal behavior and cognition.

- Females are underrepresented in much of medical research. This is problematic because side effects and effective dosages of many drugs can be very different between men and women.

- The effects of age on brain volumes are different in men and women: Men seem to lose more brain volume overall with age than women. But women lose more volume in specific regions, such as the parietal lobes.

- So, there is a strong argument for correcting this gender imbalance in medical research—in particular, so that women can benefit from treatments that are designed for their bodies, too, not just for those of men.

- Even assigning gender is more complicated than it seems. Some of these findings might not hold for individuals whose gender identity does not match their anatomy or whose sexual preferences are not exclusively heterosexual.

SUGGESTED READING

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McCarthy, Arnold, Ball, Blaustein, and De Vries, "Sex Differences in the Brain."
Murphy, et al, "Sex Differences in Human Brain Morphometry and Metabolism."
Ruigrok, Salimi-Khorshidi, Lai, and Baron-Cohen, et al, "A Meta-Analysis of Sex Differences in Human Brain Structure."

QUESTIONS TO CONSIDER

1. Is there such a thing as a male and a female brain?

2. Could you tell just by looking at it?

3. How much of the brain differences we see in men and women are a result of culture, rather than biology? Can we ever tease those 2 apart?

6

HOW ACCURATE IS YOUR MEMORY?

It's comforting to think that your brain is full of stored memories that you can access whenever you like. This is especially true of old memories. Most people believe that once these memories are stored and we've recalled them at least once, they pretty much remain unchanged until we decide to retrieve them again. But the truth is that every time you pull out the file that contains your memory, you actually have to rewrite the whole thing. And your current beliefs, emotional state, context, and other factors affect how that memory gets reconstructed and stored once again.

HOW MEMORY WORKS

> You experience the world through your senses—your eyes, ears, nose, and so on. So, you're already limited in terms of what you can remember by what you actually perceive and, importantly, what you paid attention to in the moment.

> Moreover, of all your senses, only your sense of smell has a direct route to your medial temporal lobe, the part of your brain that lays down new long-term memories. That's why smells are particularly effective in helping you remember the past.

> All the other senses make their way there but pass through at least one other region along the way, where the information is sorted, integrated with other senses, or manipulated in some other fashion.

- Sensory information makes its way to the medial temporal lobe, where it converges onto a region called the entorhinal cortex, where the information begins to form a conscious memory trace. And this is the region that is often first affected by Alzheimer's disease pathology. That's why the first symptoms in people with Alzheimer's disease are often related to forming new long-term memories.

- Psychologists distinguish short- and long-term memory not just by the time that passes, but also by what you're doing to the information. We no longer talk about short-term memory for things that we're consciously aware of; instead, we call it working memory, because to keep something in mind, we have to continue rehearsing it or otherwise manipulating it.

- Any information that you encode and access later, after a period of time—even just a few minutes, during which you weren't actively thinking about it—is considered part of your long-term memory.

- Patients with Alzheimer's disease seem to get a bit stuck in the moment. They're having trouble remembering what just happened—turning working memories into long-term ones—because the entorhinal cortex isn't functioning properly.

- Older memories can often still be accessed even fairly late in the disease, especially if they're not verbal. For example, memories of music can be accessed because they're not as dependent on the regions that degenerate first.

- When the entorhinal cortex is working properly, it sends sensory information that we've just perceived to the hippocampus, where the information is represented as a pattern of neural firing, and it gets sent around a little loop of connected cells. The hippocampus is quickly making new associations—making note of what aspects of the environment are happening at the same time, comparing this new information with what's been stored in the past, and so on.

- Your hippocampus creates a cheat sheet—it reduces the pattern of activation across many regions of your brain into a blueprint of an event. That's how the memory gets encoded.

- With remembering, your hippocampus reconstructs, to the best of its ability, what was happening in your brain while you were experiencing an event. And you have some control over this process; you can choose to take a trip down memory lane or move on to some other task.

- A new memory trace gets formed every time you remember because the hippocampus is not just recreating the original pattern; it's also changing it each time, incorporating the new information that it's receiving and disregarding things that might not be important.

- There is a bit of randomness in this process. This is both the power and the weakness of what the hippocampus does. The fact that you can imagine what it was like to be back in the past is remarkable, but it also means that it's fairly easy for you to pollute the memory with information that isn't accurate.

- The formation of a type of false memory where you combine information from different but similar events, or even insert a completely false set of details, is very common. And for the most part, it's innocuous.

- But when someone's life depends on it, as can be the case in eyewitness testimony, memory failures can be deadly. That's why

MYTH

Your memory is an accurate reflection of what happened in the past.

TRUTH

Memory is reconstructive. Each time we remember an event, we have to build up the memory from scratch, and every instance of remembering changes the way that the memory will be retrieved in the future.

we simply can't rely exclusively on eyewitness testimony, no matter how powerful it seems or how confidently the witness testifies.

> Your hippocampus acts as a pointer to the parts of your brain that need to be activated for you to reexperience an event. And the way that it does its job is changed by the circumstances of remembering—which parts of the memory you focus on, what gets retrieved, and, perhaps most importantly, what doesn't.

> If you retrieve a memory in much the same way over and over again, the parts of the rest of the brain—outside of the hippocampus—that are activated in concert begin to become associated with each other.

> When it comes to remembering, older memories that have been retrieved many times can become independent of the hippocampus. That's why the patient with Alzheimer's disease can remember things from the distant past more accurately than what happened a few minutes ago—because those distant memories had more opportunities to be retrieved and reconstructed and are therefore independent of the medial temporal lobe.

> But the feeling of reexperiencing an event and the ability to imagine its sights, sounds, and smells seems to always involve the hippocampus. We know this in part because patients with damage to their hippocampi have trouble reexperiencing memories in sensory detail no matter how old the events are. But they have preserved memory for facts about their childhood or things that happened long ago, even when they can't remember facts about things that happened recently.

> When the hippocampus is badly damaged, we see severe amnesia: an inability to form new long-term memories and, often, to retrieve memories laid down around the time of injury.

THE 7 SINS OF MEMORY

> Amnesia isn't the only way that memory fails us. Psychologist Daniel Schacter has devised a great rubric for how our memory flaws can be classified: the 7 sins of memory. There are 3 sins of forgetting or omission (transience, absentmindedness, and blocking); 3 sins of distortion or commission (misattribution, suggestibility, and bias); and the sin of persistence.

1. **Transience**. Some memories simply become inaccessible with the passage of time. They are transient. And for most people, this is a good thing. There's no need to clutter your mind with details of everything you've ever done or experienced. We've adapted the ability to pull out the important things—to remember the gist of what happened rather than every minute detail. From the gist, we can then reconstruct the full narrative if we so desire, but this reconstructive process doesn't necessarily lead to a fully accurate recollection of what actually happened.

2. **Absentmindedness**. This sin underscores the role of attention in memory. If you fail to properly encode information when it's presented to you, it doesn't stand a chance. Absentmindedness is likely the culprit behind much of everyday forgetfulness. It is evidence of the fact that we're limited in terms of how many things we can pay attention to at once. And if you're not paying attention, it's harder for the hippocampus to take note of the details.

3. **Blocking**. Sometimes the information you're trying to retrieve is temporarily inaccessible. One example of blocking is the tip-of-the-tongue phenomenon, which feels as though you know the answer, but it's just out of reach of your consciousness. Removing the stress of trying to remember often gets rid of the block. Word-finding difficulties can be symptoms of neurodegenerative diseases, such as Alzheimer's disease.

4. **Misattribution**. This sin happens when we attribute a memory to the wrong time, place, or person. Source confusions, when we misattribute the source of a piece of information, are particularly problematic in eyewitness testimony. Older adults are more prone to source confusions, and it looks like the frontal lobes are responsible for these errors.

5. **Suggestibility**. Source confusions are common, but the effects of suggestibility on memory are particularly dramatic in the work of psychologist Elizabeth Loftus. Suggestibility is the tendency to take information provided in the context of remembering and to add that information to your memory of an event. Indeed, Loftus has shown that people can be induced to falsely recall detailed memories of events that never happened simply by a specific type of leading questioning and some help from a confederate.

6. **Bias**. This sin refers to the fact that our memory of the past is skewed by our current thoughts, feelings, and beliefs. People

tend to exaggerate the overlap between their past and current selves.

7. **Persistence**. Unlike the previous sins, which represent failures in the ability to remember, this sin describes what happens when we fail to forget. Memory can be intrusive—and pathologically so for victims of trauma and abuse. Generally, persistent remembering is related to emotional memories, in which the amygdala plays an important role.

> With all of its faults, what is this kind of memory good for? The hippocampus is not just in charge of reconstructing the past; it's also intimately involved in imagination, particularly the kind that requires you to put yourself into a future scenario.

> If you compare the pattern of brain activation when you're reexperiencing a rich autobiographical memory with what's happening when you're imagining what you're going to do at some future time, there's a lot of overlap. Schacter has suggested that we've evolved this type of memory system so that we can imagine many different future scenarios and figure out what the best outcomes might be and how we might be able to get ourselves there.

SUGGESTED READING

Schacter, "The Seven Sins of Memory."

QUESTIONS TO CONSIDER

1. If memory is reconstructive and prone to inaccuracies, what is the purpose of it?

2. How should we interview potential eyewitnesses to get the most accurate picture of what actually happened?

7

DO YOU ONLY USE 10% OF YOUR BRAIN?

Do we only use 10% of our brain? Or, more specifically, is the difference between the vast majority of average humans and the elite intelligentsia the proportion of brain matter that is put to use? To answer these questions, we need to be a bit more precise. Do we mean that at any given time, we're only using 10% of our physical brain, with the rest of it lying dormant? Or do we mean that we are only using 10% of our mind's capacity, leaving 90% of our potential untapped? There are subtle but important differences between these 2 interpretations of the myth.

THE 10% MYTH

> The first interpretation is a more literal reading of the idea that we only use 10% of our brain matter in our daily lives. Some authors point to the fact that children can develop, with cognition relatively intact, despite being born with large chunks of brain missing—or that a child can recover from a complete hemispherectomy and be also indistinguishable from his or her peers. So, maybe a large part of a normal-sized brain either isn't necessary or it just lies dormant.

> Wilder Penfield, a neurosurgeon who treated patients with epilepsy, discovered that if he stimulated certain parts of the cortex, patients would have very specific experiences. Stimulating the motor cortex would cause them to move a limb, while stimulating the somatosensory cortex would induce a specific sensation of being

touched. Stimulating parts of the temporal lobe might cause them to hear music or launch them into a vivid memory.

> But there were also lots of parts of the brain that he stimulated without any observable reaction from his patients, which made him wonder if, in fact, there are regions of the brain that are underutilized.

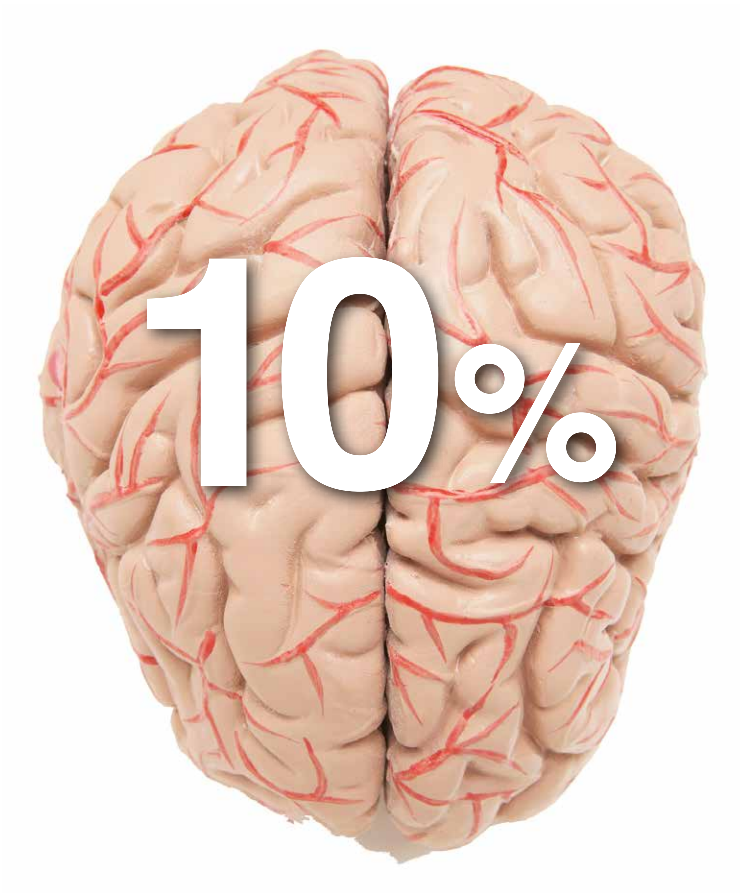
> Then there's the story of one of the most famous patients in neuroscience history: Phineas Gage, a railroad construction worker who was impaled by a rod that shot through his face and out the top of his head in 1848.

> The fact that Gage survived the gruesome accident is remarkable enough. But what's even more remarkable is that he seemed to recover his mental faculties soon after the injury, and the only long-lasting changes that doctors and friends observed were attributed to his personality rather than his mind. How could a person recover from such a massive brain injury if we truly use all of our brain matter?

> But even at the time of Gage's injury, the interpretation of what his case could tell us about brain function was hotly debated. His physician described him before the injury as hard-working and responsible and reported that once recovered, his general intelligence and memory seemed intact. But his behavior was socially inappropriate. He was unpredictable, prone to cursing, obstinate, and capricious, seeming not to care about others.

> Gage's case is among the first to suggest that the frontal lobes, where his injury was located, play a role in controlling our animal impulses and came at a time when scientists were engaged in a debate on whether the brain is modular, with different regions serving different functions, or equipotential, with every part having the potential to take on any function.

> In the first half of the 19th century, phrenology was a popular subdiscipline of psychology. Phrenologists believed that the brain



was divided into modules that were responsible for specific aspects of thoughts, feelings, and other aspects of human personality.

> Where phrenology ultimately got it wrong was in extrapolating this hypothesis to suggest that a person's mental faculties had distinctive signatures in the shape of the skull. The idea is that stronger aspects of personality would come from enlarged modules of the brain, which could be read by protuberances on the skull. We now know that skull shape doesn't predict brain shape.

- But the idea that the brain is modular, with specific regions having specific functions, remains a fundamental concept in neuroscience today. And modularity received support in the second half of the 19th century with the discovery of patients with circumscribed lesions who lost specific functions.

- On the other side of the debate, however, was the idea that the brain, or much of it, is equipotential; that is, brain matter is largely created equally and the more you have, the better your mental faculties. Similarly, the more that is damaged the worse off you are.

- Opponents of the modular view of the brain interpreted Gage's story as evidence supporting their position: His mental faculties, per se, were intact despite his extensive brain damage. Only his personality changed.

- You might argue that the literal version of the 10% brain myth is a vestige of this idea that the brain is equipotential—we have all this unused brain matter that we can just assign to something if we could unlock it. But clearly we don't need it to function as we already do. And in the 1950s, around the time that the myth was gaining ground, 2 scientists were undertaking a series of experiments that seemed to prove it right.

- After a series of experiments on rats with brain lesions, Karl Lashley and Shepherd Ivory Franz concluded that specific lesions did not lead to specific deficits; rather, it was the sheer amount of lesioned brain that dictated memory performance. The more of the brain that was damaged, the worse the rodents were at finding food in mazes.

- And almost a century before these experiments, around the time of Gage's injury, a French physiologist named Jean Pierre Flourens found that his lesioned pigeon could still fly, eat, and mate, and his frog could still learn to avoid an obstacle with only one hemisphere intact.

> Flourens was clear to distinguish between the cerebral hemispheres and other parts of the nervous system, however, and arguably his greatest contribution to neuroscience was the idea that the spinal cord, the cerebellum, the medulla, and other major brain regions have specific roles. Only the hemispheres, he thought, were equipotential and functioned as one unit.

> So, while we might need all of our subcortical structures, the cerebral hemispheres might contain all our untapped potential. By some accounts, the 10% brain myth has its origins in Flourens's work.

EVIDENCE OF BRAIN USAGE

> What is the evidence that we do, in fact, use more than 10% of our physical brains, including all of our cerebral cortex, even when we're just being cognitively lazy?

> Our brains are metabolically costly, so there would have to be a pretty good reason for why natural selection would continue to favor such an expensive organ if it was only partly used. And when we look at the activity of our brains at rest, it's clear that signals are zipping back and forth across wide swaths of our brains and no significant regions are simply quiet.

> The indisputable conclusion from neuroimaging studies is that while we might not understand exactly what it's doing, the entire brain is doing something, even when we're zoning out. Connecting this directly to the 10% myth, we can conclude that our whole brain is actively engaged even when we're resting our minds.

> Other evidence comes from patients with damage to the brain. It's virtually impossible to damage the brain to any significant extent without disrupting some aspect of mental life. Yet we still hear stories of children born with only half a brain who seem to function normally, or people who regain function after a large part of their brain is damaged.

> Thankfully, the brain does show plasticity—the ability to repair itself, albeit slowly and painfully. And this plasticity is perhaps the biological underpinning of the psychological interpretation of the 10% brain myth: that most people only reach about 10% of our psychological potential, even as we use 100% of our physical brain.

> And we need only to look at the lives of babies to see evidence for this notion: The brain is especially malleable during development. But this plasticity is limited by biology—and rightly so. Imagine how devastated you would be if all of a sudden your brain rewired itself such that you no longer had access to a lifetime of memories and carefully trained skills.

> When we think about the brain in numbers, it's difficult to imagine that we take advantage of all of its potential: 86 billion neurons with some 100 trillion possible connections is an almost unimaginable amount of potential.

> Yet, if we don't practice a skill, it begins to degrade—quickly. Complex skills are laid down in the brain after countless hours of deliberate training because the cortex, which is where much of this information is stored, is a slow learner. Unlike the hippocampus, which rapidly makes associations between co-occurring stimuli, allowing us to lay down new long-term memories, the cortex is much less flexible.

> Connections and especially learned associations are formed when 2 cells are activated simultaneously: Cells that fire together, wire together. When 2 adjoining cells are firing at the same time, the connections between them are strengthened.

> Skills and other types of information are stored in the cortex slowly, as repeated actions activate the same ensembles of neurons in similar ways. So, it takes a long time to lay down those tracks. So, biologically, we can't just say that there are easy tricks to help

us tap into some deep reservoir of potential. Developing any skill takes time—and, most importantly, practice.

> Moreover, once the brain is fully formed and well-connected (for example, in early adulthood), every part of it is in use. Any neuron that finds itself without connections dies. And by adulthood, the real estate in the cortex has all been bought up. If you don't use it for a specific ability, whatever you are using it for will be shaping the connections.

> Some regions are more malleable than others, and some periods in your life are more plastic than others, particularly during childhood, when you're learning all the important skills and information that you'll need to function as an adult.

MYTH

You only use 10% of your brain.

TRUTH

We use all of our brain—and, in fact, the reality is the opposite. If you don't use a part of your brain for one function, it will get reassigned. Cortical real estate is competitive!

> That's why it becomes more difficult to learn complex new skills, such as how to play the violin, as we get older. But it's not impossible; it's just very unlikely.

> While there is no evidence that we leave much of our physical brain idle, there is still some mystery as to how much of our cognitive potential most people achieve. And that's where individual differences come in. The truth is that your brain is a product of your experiences.

> What you spend your time doing has a huge effect on its wiring and function. So if you want to devote 20 years of your life to mastering a musical instrument, you certainly will show great improvement. And in terms of achieving a high potential in these specific skills, you'll almost certainly outstrip most people who have only spent a few years learning them.

> But time is money—and what you spend it on will limit what else your brain is able to do. So, ultimately the question is not whether we only achieve 10% of our potential but what compromises we make in terms of all the available experiences we might have during our limited time on Earth.

SUGGESTED READING

Lewin, "Is Your Brain Really Necessary?"

QUESTIONS TO CONSIDER

1. Why would anyone think that we only use 10% of our brains?

2. If we use all of our brain all of the time, how can we ever learn anything new? Is there a limit to what or how much we can learn?

8

DO YOU PERCEIVE THE WORLD AS IT REALLY IS?

Perhaps the biggest myth about how our senses work is that they reflect the world as it actually is. We do have a powerful sensory system, but it's a system that samples only a tiny portion of the environment, takes many shortcuts, and fills in details to give us the illusion that we perceive reality objectively. The way our brain perceives the world is much more complicated than taking a picture or recording a sound.

VISION

> Of all your senses, vision takes up the most cortical real estate. Our retina, where light from objects is translated into neural signals, is a flat sheet. It's 2-dimensional. So, we need to infer depth from other cues, such as which objects occlude each other, how big they are relative to one another, and where they are in one eye versus the other.

> In addition, the optic nerve that takes the information from the retina and sends it to the rest of the brain has about a million fibers. Each fiber represents information from one part of the visual field—you can think of it as a pixel.

> Your eye has a resolution of about 1 megapixel. That's a pretty inadequate camera by today's standards. The way that the eye gets around this relatively poor resolution is by concentrating much

of its fibers in the center of your field of view, so that the resolution where you focus your eyes is much better than everywhere else.

> And yet it feels as though the entire visual scene in front of your eyes is projected onto your brain with the same resolution. You just don't see the world as this tiny piece that is detailed surrounded by blurriness. You see it as having a uniform resolution. And that's because your brain is fooling you. It has adapted to give you the information you need to find food and mates and evade predators.

> The brain perceives only a small portion of the available information from the world and fills in the rest, giving us the sense that we can see, hear, smell, taste, and feel much more that we

can. This principle—the tunnel vision coupled with the filling in—is a common theme in perception.

> Even though our skin takes up more surface area than any other organ, we rely on our eyes the most when it comes to experiencing what's around us. Yet compared with eagles, who can see 4 to 5 times farther than we can, we seem to be just stumbling around in the dark.

> Even so, our visual system is truly amazing. To accomplish impressive visual feats, a huge part of our cortex is devoted to the processing of visual information—more than any other sense.

> How the visual system develops also tells us a bit about how the brain works, because it's a system that, like much of the rest of the brain, has predispositions at birth but, without the right experiences, fails to develop normally.

> The birth of neurons is just the first step in building a brain. The next step is to guide those neurons to where they need to be to make useful connections. And the third step is to wire up those connections so that they make up a functioning network. This last stage is most dependent on experience. Neurons that are isolated, that are not receiving any messages from other cells, die.

> This idea applies to many aspects of brain development, but vision is particularly sensitive to what is called a critical period: a window of time during which the right inputs need to be provided or else the system will never develop properly. That's why restoring sight in adulthood is not simple.

MYTH

You see the world as it is.

TRUTH

We experience the world through our senses, and our senses only track a tiny portion of the environment. And our senses give us only a rough sketch; the brain fills in the rest.

- The visual system is a great tool to illustrate other principles of perception, too, particularly the shortcuts and filling in that we're largely unaware of.

- Visible light travels in the form of photons—tiny packets of energy—that bounce off of objects that they encounter. Waves of light can be very short or very long, and every distance in between, and we humans can only perceive a small portion of this continuum. We've adapted to perceive photons of light that tell us what we need to know to find each other, recognize social signals, avoid predators, and so on.

- A tiny portion of the photons that are bouncing off of the external world make their way into our eyes, where they are focused by a lens onto the back of our eyeballs, where cells called photoreceptors ultimately trigger a cascade of neural signals.

- We have 2 types of photoreceptors—called rods and cones because of how they are shaped—that are distributed differently along the back of the retina. Where you focus your eyes, that part of the retina is largely populated by cone-shaped photoreceptors that ultimately provide enough information to distinguish colors.

- The cones in this part of the retina are stacked very close together and are connected to upstream cells in a 1-to-1 ratio; that is, for every cone, there is one upstream cell that captures its signal and passes it along.

- Outside of this region, cones are sparser, and rod-shaped photoreceptors are more common. Rods don't have the same luxury of a 1-to-1 relationship with their upstream cells; they have to share their signals with other rods, such that a handful or more rods send signals to the same upstream cell. And rods can't provide information about color.

> This pattern of retinal distribution and convergence on upstream cells gives rods and cones different roles in visual processing: Cones are responsible for our high-acuity vision, the small part of the visual field that we are able to see with enough resolution to read words and so on.

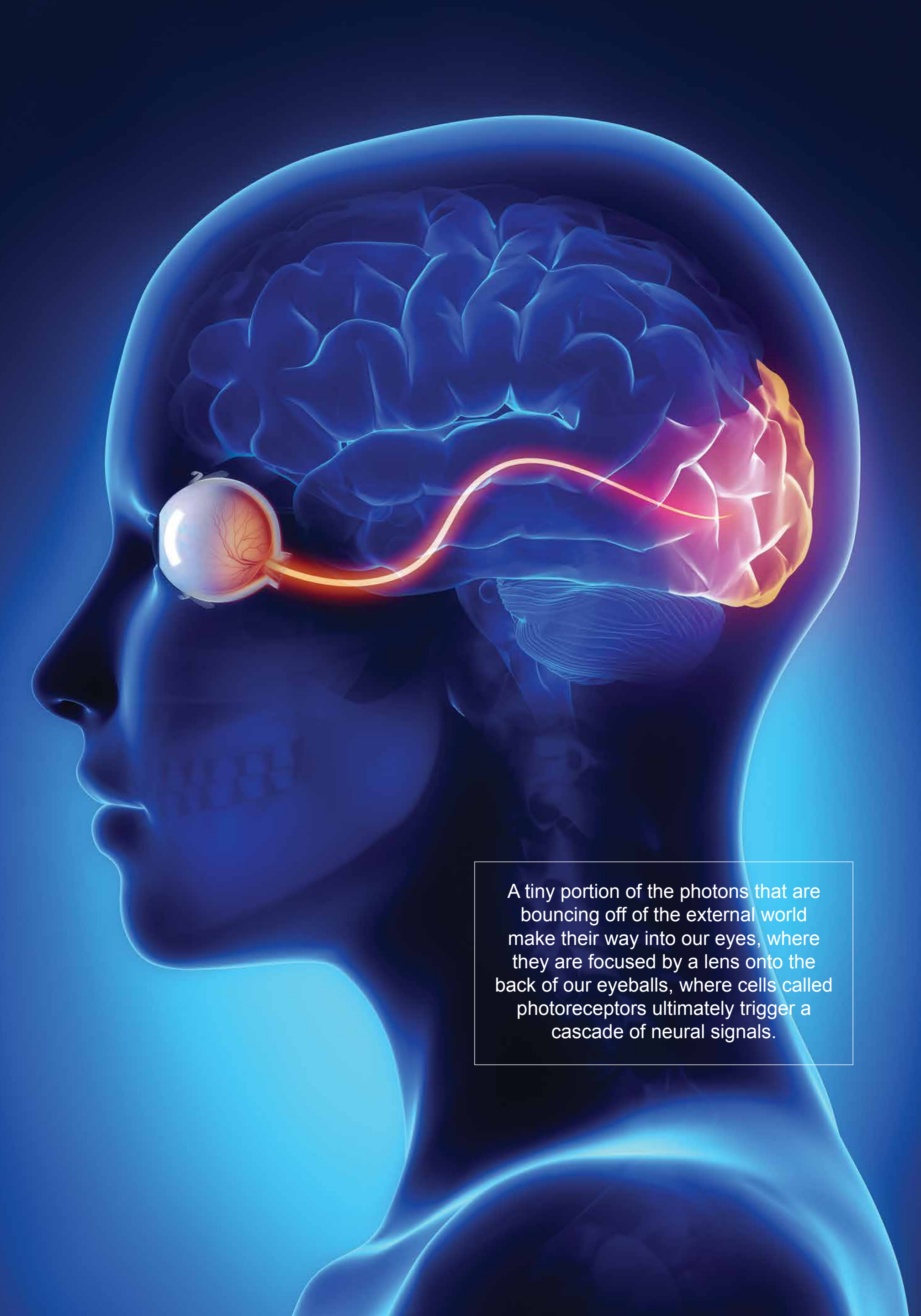
> By maintaining a 1-to-1 relationship with upstream cells, they can send specific information about light in a small part of space. And there are 3 types of cones, each more sensitive to a particular part of the wavelength spectrum. By comparing the relative activity of these types of cones, the visual system can distinguish colors.

> Rods, on the other hand, give us better sensitivity to light. Because a handful or more rods converge onto one upstream cell, if any one of them detects a photon, that upstream cell receives a message. But that cell doesn't know exactly which rod sent it, which is why your vision is blurrier in your periphery. And there is just 1 type of rod, so there is no color information.

> These upstream cells in the retina are arranged such that if a photoreceptor in their receptive field detects light, they pass along the message even farther upstream. This information continues to the thalamus, in the middle of the brain, and then to the back of the brain, where the occipital cortex is arranged in modular columns of cells.

> These columns have cells with very specific tasks. Along one set of columns are cells that respond best to bars of light in specific orientations. Along another are clumps of cells that process color information. Another region detects motion. And farther upstream are brain regions dedicated to recognizing objects.

> We know that these regions are highly specialized on the basis of 2 converging lines of research. When we stimulate them in animals, or in patients with epilepsy or other issues that require the implanting of electrodes, we see specific reactions. And when



A tiny portion of the photons that are bouncing off of the external world make their way into our eyes, where they are focused by a lens onto the back of our eyeballs, where cells called photoreceptors ultimately trigger a cascade of neural signals.

these regions are damaged with circumscribed lesions—from a tumor or a bullet, for example—patients have specific impairments.

> This argues against the myth that we see the world as it is. If that were the case, then we wouldn't see such specific impairments—you'd either see that part of the visual field or you wouldn't. Some patients have such specific visual impairments that you can't help but marvel at how modular our visual system is. One example is prosopagnosia, or face blindness.

THE BINDING PROBLEM

> Our visual system changes the initial stimulation from the retina into a set of signals that are actually useful to us as we wander around the world. Photons of light are not sufficient. We need to fill in the gaps of our vision, group stimuli into objects, recognize them, and figure out which ones are moving and where they are in space.

> We even have a blind spot in our retina, where the nerve fibers exit the eye, where there are no photoreceptors—so we can't detect photons in that part of our visual field. Yet we don't walk around with a black hole in our vision. Even though the blind spot is not that far from the center of your field of view, you don't notice it because your brain is filling it in.

> In the same way that the visual cortex fills in information from our blind spot and allows us to perceive objects as constant despite their being occluded by other objects, or illuminated with different lights, or in motion, our other senses also take liberties with the raw input.

> Each of these processes, whether they are involved in hearing, seeing, or another sense, requires a different set of computations, often accomplished in disparate regions in the brain.

- The fact that vastly different parts of the brain process the nuts and bolts of different senses goes against our subjective experience of the world. It doesn't feel like your eyes are seeing one thing and your ears are hearing another; the whole perceptual experience feels seamless.

- This paradox is what psychologists call the binding problem. How can a modular organization of the brain lead to a seamless subjective experience of the world?

- We can learn about how the brain solves the binding problem, at least when it comes to vision, by studying what happens when it makes an error.

- In its simplest form, binding is the brain's way of combining 2 distinctive features—for example, color and shape—into one coherent percept, such as a blue circle. But under some conditions, we can catch the brain making a mistake, called an illusory conjunction, for example, when it sees a blue circle embedded within green squares and interprets one of the objects as being a blue square.

- We see more of these illusory conjunctions when we are not paying attention to the object directly—either we're distracted by something else, or it's in our peripheral field of view, or a similar object is nearby.

- Patients with damage to the left parietal lobe, a part of the brain called an association area that seems to be involved in bringing information from different senses together, make more of these types of errors. For example, patients with simultanagnosia can't perceive more than one object at a time simultaneously.

- We still don't know exactly how binding happens, but probably the best hypothesis is the idea that binding is an emergent property of the synchronization of many neurons firing. When the neurons begin to fire in synchrony, with the same oscillations, the idea

is that the perception of different features becomes bound into one object.

> Synchrony is attractive as a hypothesis because it can be flexible, changing according to the conditions and a person's attention and dynamic, quickly binding features together. It can also happen across long distances in the brain and can be modified with learning.

SUGGESTED READING

Treisman, "The Binding Problem."

QUESTIONS TO CONSIDER

1. How should we answer the following question from the perspective of a psychologist: If a tree falls in the forest and there is no one there to hear it, does it make a sound?

2. What would our lives be like if we could sense a completely different set of physical stimuli?

9

IS YOUR BRAIN TOO SMART FOR MAGIC TRICKS?

It is a myth that our senses are objective: that we might not process all the information available to us and our senses might take some shortcuts, but they don't just make stuff up—what we see and experience through our senses is out there somewhere. We are so used to thinking that our perceptions represent a true and accurate picture of the world that we are more likely to attribute a magician's success to some mysterious and supernatural force—magic—than to consider our own minds as the source of the fault.

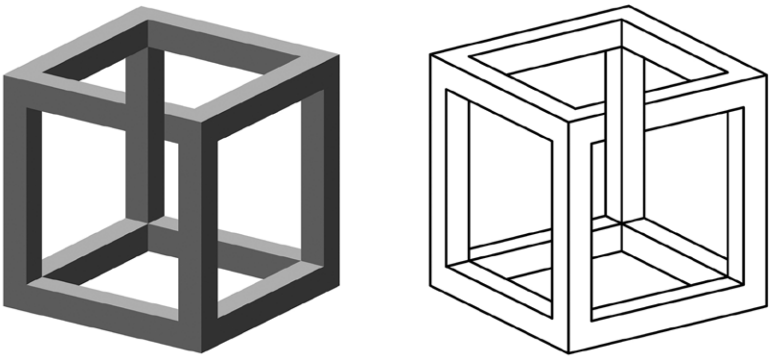
SELECTIVE ATTENTION AND INATTENTIONAL BLINDNESS

> We actually perceive very little of the world directly—our 1-megapixel eyeballs are a blurry window—but our experience trains our brain to develop effective shortcuts and to fill in missing information. Not only are our senses limited by the physics of capturing so much available information, but we are also limited by our ability to process it.

> Despite claims that our brains are the most complex thing known to man, we are only able to pay attention to a remarkably small amount of information at any given time.

> In fact, when the brain can't make immediate sense of some sensory information, as is the case in ambiguous or impossible figures, it will choose an interpretation for you. A classic example

of this situation is the Necker cube—a 2-dimensional figure of a cube that can be interpreted in 2 ways, either projecting backward in space or forward.



> Why can't our brains handle ambiguity? Wouldn't that give us a clearer and more accurate view of reality? The answer brings us back to attention.

> Instead of fully processing all of the sensory information available to us, our brains have to triage what's most important. And just like in the ER, the way we triage depends on how big the emergency is. If there is a crisis, our attention can be directed to some very specific part of the environment. A loud crash or a large earthquake will immediately grab your attention away from even the most engrossing film or task.

> We call this type of attention grabbing a bottom-up process; that is, something in the world surrounding us triggers a big response in one of our senses, and this response overrides our efforts to focus on something else. Our attention is drawn away from whatever we were doing and toward the source of the stimulation.

> Depending on what we're doing, we can be more or less distracted by our surroundings. If we're bored, we might more readily turn

our attention to something potentially more interesting. If we're fully engrossed in what we're doing, however, we might ignore all but the most earth-shattering disruptions.

> This attentional focus is a continuum—not an either/or. And it takes time to become focused enough to tune out most of the distractions around us. That's why multitasking is so inefficient.

> Most of the time, we direct our attention to different aspects of the environment that interest us. That's what psychologists call top-down' processing. We have a limited amount of attention; there are only so many things we can monitor at once. And the more we concentrate on one thing, the less attention we have to spare for other things.

> But as we concentrate on this or that specific activity, we overestimate just how much attention we are paying to the rest of our surroundings. We think we still see and hear the "big things," but we often don't. This overestimation of how good our perceptual system is at keeping track of what is going on outside our immediate focus is what magicians are counting on.

MYTH

Your brain might fill stuff in, but it doesn't outright lie to you.

TRUTH

Illusions are present in all of our senses and can give us an idea of how the brain accomplishes the difficult task of perceiving the world.

> Our failure to register an unexpected event when engaged in a fairly trivial task is called inattentional blindness. We are blind to things that we're not paying attention to, even when they are directly in front of us.

> Inattentional blindness explains why we lose our wallets or keys in plain sight. And it's also exploited by magicians.

> Vision researchers Stephen Macknik and Susana Martinez-Conde joined forces with veteran science writer Sandra Blakeslee to illustrate how magicians capitalize on the brain's shortcomings in their book *Sleights of Mind*. And one of these shortcomings, arguably the most powerful one, is inattentional blindness.

SITUATIONAL AWARENESS AND CONFIRMATION BIAS

> Many magicians, having learned just how precarious our attentional system can be, train themselves to overcome their limitations and become attentional experts. Then, when they demonstrate their new superpowers, we attribute it to magic.

> One example is an improvement in something called situational awareness, which involves keeping track of what is happening where at all times, understanding what these happenings mean, and being able to predict what is about to happen.

> Magicians can become experts at noticing things. Mentalists, people who claim to have some extrasensory perception, are usually hyperaware of what's going on. They constantly scan the environment and notice trivial things that most people ignore but that can give them crucial information about their subjects.

> Eric Mead, for example, a mentalist described in *Sleights of Mind*, can impress his dinner companions by keeping his eyes focused on the guests at his table while describing the people dining at other tables around the room—how many of them are at each table, what they look like, what they're eating, and so on. And he can even give details about their lives.

> Mead can do all of this because he has trained himself to be hyperaware of his surroundings, and he can incorporate this skill into his magic acts. Making these observations, without the targets of his attention noticing, gives him the ability then to make surprisingly accurate claims about the lives of people who attend his

shows—so accurate that he's able to convince people that he can predict their future or commune with their deceased loved ones.

- Mead's expertise in situational awareness works especially well in his act because he can couple it with people's tendency to look for evidence that confirms their beliefs, rather than disproving them. This tendency is called the confirmation bias.

- Mentalists are masters at exploiting our confirmation bias. But most people are not quite so astute at noticing the details of our surroundings. And for the most part, this is a good thing, because it allows us to focus and remember the things that are really important—such as what's changing.

- Most of our perceptual processes are geared toward noticing change, because if something in the environment is still the same and we're still alive and well, it's probably not life-threatening. It's change that can be scary.

HABITUATION AND CHANGE BLINDNESS

- All of our senses—our visual system, auditory system, sense of smell, sense of touch, and so on—and even our cognition are susceptible to habituation: When we encounter the same stimulus or situation over and over again, we begin to stop responding to it, or ignore it altogether.

- An example of habituation is what happens when you move into a new house. The first night, every little creak and odd sound wakes you up and draws your attention. But over time, and fairly quickly, you learn to sleep through all the regular sounds, as your senses habituate to your new home. But a strange sound, such as a neighbor playing the radio, even if it's in the same decibel range as your refrigerator, for example, all of a sudden pulls you from your slumber.

- Habituation happens with your sense of touch, which is why you don't feel your clothes most of the time, and it happens with your sense of smell, which is why we don't usually smell our own body odors.

- It also happens with vision. Arguably the best illustration of habituation in vision is a phenomenon called change blindness, which is our inability to notice change—even big changes. This explains why movies can get away with many mistakes. Objects, the positions of actors, and even hair and makeup can change between shots without the audience crying foul and being pulled out of the story.

- Change blindness most often occurs when the change is gradual or slow and outside of the immediate focus of our attention. For example, if 2 actors are shooting a scene at a coffee shop, we probably won't notice (unless we're specifically looking for it or our attention is drawn to it) exactly where their coffee cups are from shot to shot or how much liquid is in them. But if suddenly one of them had a gash across the face or was wearing glasses, we would likely register that because we'll have been paying attention to their facial expressions.

- We generally process faces holistically: We pay attention to the relative positions of facial features, such as the distance between the eyes and the relative size of the nose and mouth, instead of focusing on each feature separately, the way we would if we were looking at some other feature, such as the placement of a person's coffee cup.

- Change becomes more difficult to detect as we get older and might explain part of the decrease in driving ability with old age. Older adults might not notice changes in an intersection, for example, as quickly as younger adults, leading to a higher risk of accidents.

> Change blindness is also a problem for eyewitness testimony, as the witness wouldn't notice if there was a change in the identity of a target person before and after a crime.

> Worst of all, most people have change blindness blindness; that is, we don't know that we don't know. We're unaware of just how bad we are at detecting slow changes or changes that are outside of our attentional focus.

> But change blindness illustrates something fundamental about our brains: the fact that we're actually pretty good at detecting salient, or important, changes. In fact, we thrive on stimulation; in the absence of any changes in our environment, our brains stop functioning properly. That's why sensory deprivation can drive you insane.

HALLUCINATIONS AND ILLUSIONS

> If you deprive yourself of one sense—for example, by wearing a blindfold—you can heighten another sense, such as hearing. In the short term, though disorienting, sensory deprivation can be relaxing. There are even spas that sell you such experiences.

> Deprive yourself of stimulation for too long and you can develop extreme anxiety, depression, and hallucinations—your brain will create the stimulation for you. And sensory deprivation has been used by many governments as an interrogation technique, skirting the line between acceptable tactics and torture.

> These hallucinations aren't just auditory or visual; even our sense of touch can create illusory stimulation in the absence of real experiences. Perhaps the most famous cases of illusory sensory hallucinations are patients with amputated limbs. A common problem in such patients is the frustrating sensation that the missing limb is itchy or painful.

> Illusions tell us that our experience of the world outside our brains is anything but direct: Our senses are not independent of each other, nor are they untouched by our previous experiences. We can only perceive a small sliver of all the available information out there in the world—a small portion of light, sound, touch, and other ways in which the world can affect us.

> But our brains have been shaped by evolution to extract the critical details and fill in the rest, leaving us prone to illusions but also enabling us to thrive in the little patch of the universe that we call home.

> And these illusions are influenced by our past—the language we speak, in the case of auditory illusions, and the things we pay attention to in the case of our visual environment. Despite folk wisdom to the contrary, our senses are far from objective.

SUGGESTED READING

Botvinick and Cohen, "Rubber Hands 'Feel' Touch That Eyes See."
Rattan and Eberhardt, "The Role of Social Meaning in Inattentional Blindness."

Simons and Chabris, “Gorillas in Our Midst.”
Stetson, Fiesta, and Eagleman, “Does Time Really Slow Down during a Frightening Event?”

QUESTIONS TO CONSIDER

1. How much control do we have on our attention?

2. If we can induce the illusion that a rubber hand is our own appendage, what happens when we spend a lot of time driving a particular car or interacting with the world through some kind of machine?

10

IS YOUR BRAIN OBJECTIVE?

We look for, and often find, patterns. Our brains are so efficient at detecting these patterns that we often err on the side of seeing meaning in something that, in fact, is just random noise. What we're not really good at is quantifying random noise—calculating the odds of the pattern occurring just by chance. Furthermore, we're predisposed to evaluate our beliefs by looking for evidence that confirms, rather than disconfirms, them. This is called the confirmation bias. And it's the truth that busts the myth that we weigh all evidence equally and build personal theories only after considering the data—which we don't.

CONFIRMATION BIAS

> We're pretty good at recognizing when things repeat in the environment—at noting coincidences. We're not very good at figuring out how likely those coincidences are in a world governed by chaos. We don't take into account base rates, or the raw likelihood of an event happening without intervention.

> If we were fully rational about the beliefs we hold and the conclusions we reach, we'd always follow the insight of Thomas Bayes, who first proposed the Bayes theorem. He realized that to understand the likelihood of a given situation, we need to take into account the base rates—it's not enough to consider confirmatory evidence.

> But our brains don't seem to be wired that way. It seems more natural, more instinctive, for us to reach for evidence that readily confirms beliefs we've already formed or that supports whatever conclusions we find most "obvious."

> It makes sense that people are selective with what type of evidence they consider when evaluating beloved beliefs that they are motivated to maintain. People who want to believe in the existence of a higher power, for example, and who see miracles as evidence for such an existence might be motivated to look for evidence that a miracle happened rather than considering evidence that supports a simpler explanation.

> Our brains have evolved to find meaning in our world. We search for evidence that confirms our beliefs. And we pull it into a story that helps us make sense of chaos and the frightening thought that the universe is random.

> The confirmation bias captures the fact that your beliefs and opinions are based on cherry-picked data: years or even decades of situations in which evidence that confirms them grabbed your attention, while disconfirming evidence was ignored. It's why sometimes when you learn a new fact or become engrossed in some topic, elements of that theme seem to follow you everywhere.

> The confirmation bias is especially rampant in political debates, where candidates cherry-pick data points to support their policies, rather than creating policies based on all the data. The climate debate will go down in history as a prime example. For every new study demonstrating the link between human activity and climate change, deniers point to a data point or 2 showing that parts of the Earth are cooler now than they were in the past. This is a very human thing to do.

> In fact, even when the hypothesis to be tested isn't a pet project, people still tend to search for confirming rather than disconfirming evidence. Why?

- Part of the answer comes from work showing that we're just not very good at calculating or considering probabilities. The world is vast, and there's a lot going on at any given moment. So, coincidences are common.

- Yet we have a built-in tendency to correlate or even infer causality when 2 things happen close in time. Or when we hear a story about something that we think is pretty rare but forget that the world is vast and the number of people in it is staggering, we attribute a special aura to something that is much more ordinary that it might seem.

- This type of inferred causality and confirmation bias can even be readily apparent in certain disciplines that sound scientific but that really are pseudoscience: claims that seem to be grounded in the scientific method but actually aren't.

> MYTH
>
> When we're testing our beliefs, we evaluate all the evidence equally.
>
> TRUTH
>
> Our brains are pattern detectors: We look for regularities in the environment, and this tendency means that we search for evidence that supports our beliefs rather than information that might challenge them.

- If you take enough measurements and massage them in just the right way, you'll find numbers that correspond to whatever it is that you want to believe. The different ways that we can interpret and play with numbers are infinite.

- This is even a problem in neuroscience. It's especially prevalent in neuroimaging, where statistics play a central role. The premise for many studies is that different parts of the brain are responsible for different functions. So, by tracking the activity of the brain while a person is performing a particular function and comparing it to what's active when he or she is doing everything other than that function—lying in the noisy MRI machine and listening to the

clicks, etc.—we can see which brain regions are most involved in the function that we're trying to isolate.

> But you're using your entire brain most, if not all, of the time. So, by setting your statistical threshold fairly low and not correcting for multiple comparisons, you can pretty much find activation in any part of the brain during any task. If you're looking to confirm a hypothesis, you have a gold mine of data to pick from. But that's not how science is supposed to work, of course. Even neuroscientists, who know better, get sucked in by the confirmation bias.

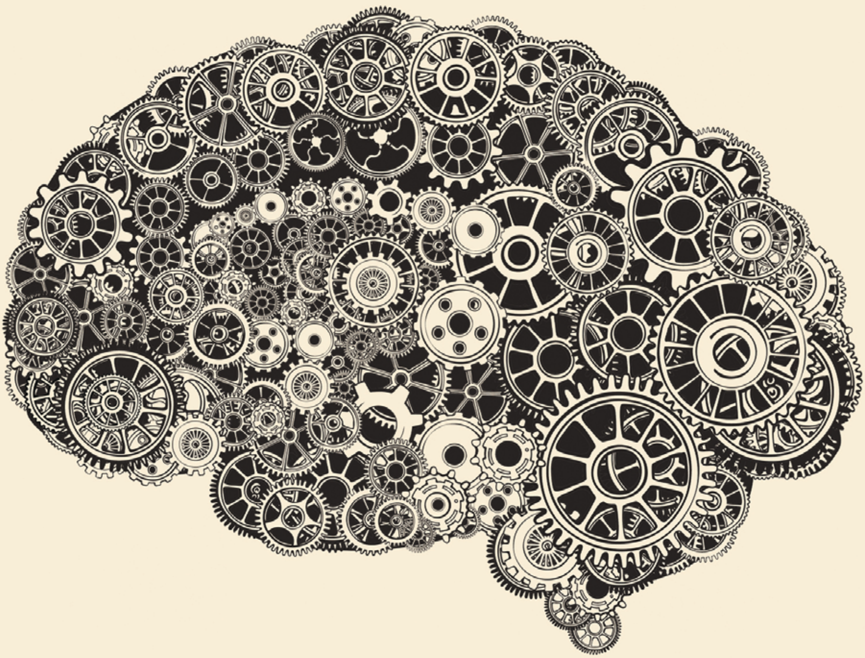
THE POSITIVE AND NEGATIVE SIDES OF CONFIRMATION BIAS

> Is the confirmation bias a bug in our brain that we could do without? No, because it's part of the pattern-detection process that also gives us some truly sublime experiences—such as appreciating music. Repetition is found in music across cultures and genres, and there are many more repetitions in music than in regular speech.

> Our brains have evolved to be efficient pattern detectors. We search for meaning in even the most ambiguous things, because it might have been adaptive for us to mistake the leaves for a leopard rather than fail to notice a predator. This tendency explains why you often see faces in clouds, cliffs, or other ambiguous things. We've adapted to err on the side of seeing a pattern where there might not be one so that we do not miss any important connections.

> And we enjoy finding these patterns. We love solving these little puzzles; it makes life just a little more predictable. When we detect a new pattern, we actually get a little surge of enjoyment: In neuroimaging, we see a surge of a neurotransmitter called dopamine, which is involved in our experience of pleasure.

> Our brains are wired to look for patterns, so our search for patterns—for meaning—in images, music, and events is both



automatic and often intensely pleasurable. Some people argue that meaning is what makes life worth living. We hold tightly to the need to connect with our world and each other.

> So, we tend to look for evidence that confirms our existing beliefs, thoughts, and feelings. Even when we are testing an idea, we often succumb to the temptation to look for confirmation rather than evidence that would demonstrate that we're wrong.

> We see this bias across many different fields and domains, and it can have negative effects. It can lead to superstitious beliefs, some of which can be harmful. It can cause paranoia and prolong depression. Snake-oil salesmen and other peddlers of misinformation can exploit our confirmation bias and use it

to deceive us. And it can perpetuate stereotypes and hostility between different groups of people.

> This last negative effect of the confirmation bias—that it can drive people apart into camps of “us versus them”—has been illustrated in a number of studies. One of these was famously conducted in 1979 by Charles Lord, Lee Ross, and Mark Lepper, who were interested in understanding how the confirmation bias might contribute to attitude polarization, an increase in disagreement between 2 groups of people when presented with more evidence.

> We see this effect when it comes to emotionally evocative issues—usually ones that tend to be political in nature, such as gun control, gay rights, and capital punishment.

> In line with the confirmation bias, Lord, Ross, and Lepper found that when people were given studies investigating capital punishment, people reported that the studies that they read that were in line with their original opinion on capital punishment were more convincing than the studies that they read that were not in line with their opinion on the issue.

> They said that the studies that were in line with their original opinion had fewer flaws and better methods—in short, the science was more sound. And they held their position even more strongly at the end of the experiment, even though they had been presented with evidence both for and against their stance.

> What are the benefits of the confirmation bias? The answer to that question lies in the fact that beliefs largely bring people together; they can serve as social glue and, as such, are important facets of society.

> Of course, we don’t live in the savannah anymore, so as our society shifts, we now see how beliefs can actually create large rifts. But our brains didn’t evolve to test scientific theories. They

evolved to help us survive in harsh environments, among many complicated members of our species.

> And many of these beliefs are not falsifiable; they are too grand and complicated to be rendered untrue by a simple test. So, maybe in those cases, it doesn't work to throw out a good idea on the basis of one counter-indication.

> If you believe that people are fundamentally good and then someone makes a mistake and hurts your feelings, it doesn't do you any good to then throw out the assumption that most people, or even that person, is actually a friend rather than a foe. That fundamental belief is what gives you the power to forgive and mend fences. And finding meaning in a chaotic world can enrich your life. But it makes objectivity something that you have to work on, not something that comes naturally.

SUGGESTED READING

Nickerson, "Confirmation Bias."

QUESTIONS TO CONSIDER

1. How can we recognize confirmation bias in our own decision making or weighing of evidence?

2. How much evidence should we consider before we change a belief?

3. What might the benefit of a confirmation bias be?

11

DO YOU HAVE 5 INDEPENDENT SENSES?

The idea that we experience the world through 5 senses is ingrained in our culture. The magic number 5 has a lovely order to it—corresponding to our eyes, ears, nose, mouth, and skin. And when we talk about some sensation other than what can be captured by these body parts, we call it a "sixth sense." But the notion that we have only 5 independent senses is a myth. We have many more, and they influence each other and our behavior to a great extent.

SENSES OTHER THAN THE BIG 5

> Psychologists distinguish sensation from perception, with sensation referring to the process by which our sensory cells are stimulated by light, air, chemicals, and so on, and perception being the ways in which our brains turn those signals into usable information about the world. Sensation is about detection; perception is about interpretation so that we can act accordingly.

> We generally think about sensation as a passive process; we are receivers of stimulation. And we think of perception as an active process; we have to do something with the information to use it wisely. Perhaps, then, we should talk about sensation as being objective, but perception is where our past experiences, and other factors, muddy up the data. But the truth is that sensation is useless to us without perception.

- So, if we think about our senses as just the first step in the process of choosing what to do next—or how to behave—we can divide them into 2 categories: near and far, designating the distance between the stimuli that we're responding to and ourselves. From the magic 5, near senses are smell, touch, and taste, while far senses are hearing and seeing, for example.

- When things are close, as is the case with noxious chemicals, a toxic food, or a burning candle, we have to act quickly and reflexively. We don't have time to think about it. But our far senses, seeing and hearing, give us information about things that are farther away, so we can spend more time analyzing the data and filling in details, such as depth, color, lighting, and texture.

- Just knowing where things are is useless to us if we don't know where we are; that is, you can't pick up an object if you don't know where your hand is. And we don't just use vision to figure out where our body parts are—we can feel them even if we close our eyes.

- This sense is called proprioception, and it has its own set of receptors called spindles, embedded deep within our muscles, that track how stretched out each of our muscles is. They respond to changes in the length of the muscle; when you move a body part, the spindles track how your muscles change.

- Although proprioception does tell you where your own body parts are even when your eyes are closed, there is an interplay between vision and proprioception. We can observe this interplay at work in an often-ignored sense: our sense of balance.

- Within our ear canal are 3 perpendicularly arranged loops filled with fluid. As we move around, gravity acts on the fluid in the loops, and it moves in particular ways. We have cells there that sense the movement of the fluid, and then our brain calculates where our heads are with respect to the floor.

> If we get an ear infection and these loops swell, for example, we can experience debilitating vertigo: Every time we move our head, we get extremely dizzy, as the messages from our inner ear do not correspond to what we're sensing via proprioception and vision.

> By some accounts, the loss of this vestibular sense is worse than losing your vision or hearing, because at least when you're blind or deaf you can still move around in the world without feeling utterly sick.

> In addition to proprioception and the sense of balance, you can also sense when it's been a while since you last ate or drank. That's because your body also tracks hunger and thirst. Fatigue is another state that we're able to sense.

> We even have a set of chemoreceptors that are activated when there is too much carbon dioxide and too little oxygen in the cerebrospinal fluid, the fluid that protects and supports the brain and spinal cord, prompting signals that change how you're breathing. We have the ability to sense and act on changes in the acidity of our cerebrospinal fluid.

> Beyond proprioception, we can also get signals from our body when it's being damaged: We feel pain. Pain comes in many forms, and like vision, hearing, and other senses, it's complex and subjective.

> Despite the fact that it makes us miserable, pain is also life-saving. People who are born with a condition that renders them insensitive to pain have a shorter lifespan than the majority of people, who suffer with every paper cut.

> Pain can roughly be categorized into 3 causes: neuropathic, occurring when nerves, the spinal cord, or the brain is damaged; nociceptive pain, when there is tissue damage, for example, from a cut or a broken bone; and psychogenic pain, where the cause is unclear and may be related to mental, emotional, or behavioral problems.

- Like Anton's syndrome, where an individual is blind but denies that he or she can't see, we can sense pain without feeling that it's unpleasant. Morphine, for example, can remove the unpleasantness of pain without removing the sensation altogether. Yet, as with impairment to your vestibular sense, pain can be so debilitating as to cause a person to prefer death rather than to continue to live in such suffering.

- But because pain is so subjective and difficult to describe, there are often inequalities with respect to how it is managed. African Americans, for example, have been found to be undertreated for pain in U.S. hospitals and clinics, compared with their white counterparts—as are women, compared with men.

- This difference in treatment is cultural and underscores the complexity inherent in describing a sensation. One way that scientists who study perception have tried to address this problem is by focusing on the unique types of receptors that we have.

MYTH

You taste food with your tongue, and different parts of your tongue taste 1 of 5 different flavors: bitter, salty, sweet, sour, and umami.

TRUTH

Taste perception is much more complex than simply where food hits your taste buds. In fact, taste is largely based on smell.

- For touch, for example, we have receptors that track tissue damage—nociceptors—and give us feelings of pain. But there are also receptors for temperature—distinguishing cold from hot—and for mechanical pressure and even itch, called pruritic receptors. There's even a special class of nerve fibers that tracks pleasurable but nonsexual touch.

- Just like vision, which can be better or worse in different people depending on physical features of the eyes, pain and other elements of touch can also show individual differences. For example, 2 people can have different densities or amounts of pain receptors in

different parts of their bodies. But individual differences are perhaps most notorious in our sense of taste, or gustation.

> The sense of taste is mired with yet another myth: that the tongue is divided into sections, with each one responsible for a different taste. The threshold of sensitivity—that is, how much of a stimulus you need to detect a particular taste—varies slightly across the tongue, but the intensity of taste does not. All parts of the tongue are capable of tasting sweet, salt, bitter, and sour.

> But what does seem to make a difference is your own individual taste bud distribution. Some people, dubbed supertasters, have many more taste buds than other people. Supertasters can taste things that other people cannot—and their experience of taste is heightened.

SENSORY CROSSING

> Another myth that studies of how we perceive flavor have helped debunk is the idea that each sense operates independently of the others; that is, what we see doesn't affect what we hear, and vice versa.

> Anyone who has had a cold knows that our perception of flavor is highly influenced by our sense of smell. For example, adding vanilla to food is about aromas, because you can make something taste sweeter by adding a caramel or vanilla odor. Vanilla tasted on its own is not that sweet. In fact, for most people, it's rather tasteless. But add it to a sugar solution and all of a sudden the pairing is sweeter than either ingredient alone.

> This correspondence between odors and sweetness is at least partially a learned response: In countries where odors such as vanilla, caramel, strawberry, and mint are often paired with sucrose, people report that food tastes sweeter with the addition of the odor. But in countries where these pairings don't happen as

often, the tasters don't report an enhancement in sweetness with the odor additive.

> And novel smells, such as lychee to Western noses, can become sweetness enhancers if they are repeatedly paired with sucrose.

> One of the earliest and most dramatic demonstrations of how intertwined our senses of sight and hearing are comes from a study in the 1970s that reported the existence of the McGurk effect, named after the author, Harry McGurk.

> McGurk set out to test the idea that speech detection is exclusively an auditory phenomenon: that we only use our ears to understand spoken words. And if you just listen to a soundtrack of someone speaking, you can understand it perfectly well.

> But what happens when you watch someone speaking and what they are saying doesn't match up with what your ears are sensing? Do you just hear the correct speech but notice that the movement of the mouth isn't quite right, or do you not notice anything amiss at all?

> The McGurk effect is something that purveyors of dubbed films have been counting on for decades: When what you see doesn't correspond precisely with what you hear, your brain makes up for it.

> In the original paper, McGurk and his colleague John MacDonald describe an observation that when you see a woman say the syllable "ga" but hear the syllable "ba," you perceive the sound "da." They replicated the results with a video of a person saying "pa" but with a soundtrack saying "ka," which leads observers to report hearing "ta."

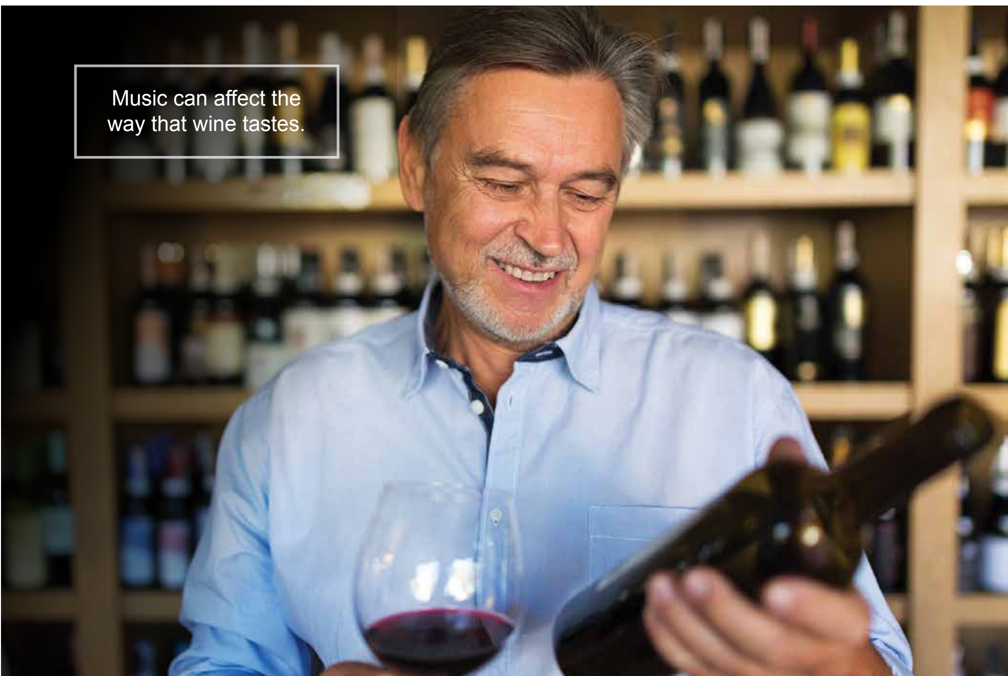
> Interestingly, McGurk and MacDonald ran the experiment using children and adults, and the children were better listeners: They were more likely to report the correct syllable as per what they were hearing, while the adults were more likely to be influenced by

the visual aspects of the task. But within each group, the illusion of hearing a fused response—a third syllable—rather than either of the 2 actually presented persisted.

- Even distinctions between the near and far senses need to be revisited. Studies have shown that just by adding food coloring to change the color of wine from white to red during a wine tasting, our tastes are affected. When the wine looks red, we use descriptors more appropriate to red wine rather than white wine, even if what we're tasting is actually white. And wine connoisseurs aren't immune to this phenomenon.

- Simply changing the label of a wine affects how much we report liking it. If the label says it's from a superior vintner, or if we paid more for it, we'll use more positive adjectives when describing it than we would if it were labeled as a common table wine.

- Background sounds, and music specifically, can affect the way that wine tastes. In one study, the type of music—powerful and heavy,



subtle and refined, zingy and refreshing, or mellow—influenced the adjectives that the tasters used to describe the wine they were tasting while the music was playing.

SYNESTHESIA

> There are people for whom sensory crossing is heightened: synesthetes. Synesthesia is a neurological condition in which stimulation of one sense causes the involuntary activation of a different sense. The most common type of synesthesia is called grapheme-color synesthesia; people with grapheme-color synesthesia see letters and numbers in color.

> Other forms of synesthesia include associating sounds with colors, such that a car honking might evoke the color blue or sounds might evoke tactile sensations; or words with tastes, such that the word "soccer" might evoke the taste of bananas.

> We don't know how synesthesia develops, but it does run in families and it also seems to emerge in childhood. And every year, we seem to discover new crossings and new insights into our senses, making it clear that we're far from done with respect to understanding our subjective experiences of the world.

SUGGESTED READING

Auvray and Spence, "The Multisensory Perception of Flavor.
McGurk and MacDonald, "Hearing Lips and Seeing Voices."
North, "The Effect of Background Music on the Taste of Wine."

QUESTIONS TO CONSIDER

1. What neutral odors have you associated with specific tastes?

2. Can you think of any sensory crossings that you might have experienced?

12

CAN CERTAIN FOODS MAKE YOU SMARTER?

We seem to be overly eager to embrace the idea that there are certain foods that can improve our brain's function. How does what we put in our mouths end up in our brains? There are myths associated with fish oil, vitamins, power drinks, and antioxidants. In general, eating a healthy diet and getting daily exercise is good for your brain. Excessive consumption of pretty much anything is not.

HOW NUTRIENTS REACH THE BRAIN

> The way nutrients reach brain cells is a bit different from the rest of the body. That's because brain cells are precious. We don't want to lose them because they don't replenish the way, for example, our skin cells do.

> The immune system largely functions by killing cells infected with foreign invaders. We can't use that system in the brain the same way that we use it in the rest of the body. Instead of sending out troops of killer cells, nature built a fortress around the brain, called the blood-brain barrier. It's essentially a network of blood vessels with cells that are much more tightly packed, preventing large molecules from being able to cross into the brain.

> But that means that important nutrients are also shut out. So, the brain has a complex system of cells that do security checks, letting

MYTH

Eating certain foods will make you smarter.

TRUTH

Eating a healthy diet is important for brain health because the brain is so metabolically expensive. But so far, there aren't any foods that consistently improve cognitive functions.

in the good nutrients and passing them along to the right brain cells, and keeping out the suicide bombers—for the most part.

> The brain is a metabolically costly organ, taking up only 2% of body mass but guzzling around 20% of its fuel. That's why it's difficult to think when your blood sugar is low.

> But providing glucose is not the only way that food can influence the brain: It also provides certain cellular building materials and can play a role in neuroplasticity, or how cells change with experience. These changes can even include epigenetics, switching genes on or off and affecting how they are expressed, meaning that what you eat can ultimately shape your brain.

> Some foods, for example, can trigger the release of certain hormones that can then affect brain function. One of these hormones is called brain-derived neurotrophic factor (BDNF), which has a number of jobs, one of which is to guide and promote the growth of new neurons and the connections between them.

> It's very active in the hippocampus, which is where our short-term memories are turned into long-term ones. The hippocampus is our window both to the past and to the future; we need it to travel backward in time in our memory and forward in time in our imagination.

> Because it plays a big role in shaping the hippocampus, BDNF is important for long-term memory formation. If you put an animal—human or otherwise—in an enriching environment, for example, more BDNF will be produced in his brain, leading to more synapses, more dendrites, and more neurons, the ultimate effect of which is that the animal learns more. It gets smarter than an animal raised in an impoverished environment, whose brain has lower levels of BDNF and fewer of these changes.

FISH OIL

- The key ingredient in fish oil is omega-3 polyunsaturated acid—specifically, docosahexaenoic acid (DHA)—and you might have heard claims that it's good for your brain. You can find it in oily fish, such as salmon, mackerel, and sardines, or you can take it as a supplement. DHA is thought to play a role in brain development by increasing the expression of BDNF.

- From work with rodents, we know that omega-3 fatty acids turn on genes that help keep the signaling system between brain cells working properly and enable neuroplasticity, or the types of physical changes that drive learning.

- DHA is the most prevalent fatty acid in brain cell membranes—the protective covering that keeps the good stuff in the cell and the bad stuff out—but that also plays a major role in signaling between cells.

- There's some evidence that our ability to add DHA to our diets was a turning point in our evolutionary history, helping our brains grow in size compared with the rest of our body—increasing the brain-to-body-mass ratio, or encephalization quotient. DHA is also an antioxidant.

- DHA supplements are recommended by the American Heart Association because they seem to reduce the risk of coronary artery disease. And cardiovascular problems contribute to cognitive decline. Eating a lot of fish also seems to be associated with a lower risk of stroke.

- They also reduce inflammation, which has been associated with neurodegenerative diseases such as Alzheimer's. And omega-3 fatty acids might even play a direct role in decreasing Alzheimer's pathology because they reduce amyloid production and the plaques that are a signature of the disease are made up of amyloid.

> Fish oil likely won't make a difference unless you're pregnant, under the age of 1, or at risk of showing cognitive impairment, either in childhood or in old age. There doesn't seem to be any evidence of DHA to make you smarter.

ANTIOXIDANTS

> We often hear good things about green tea, coffee, chocolate, red wine, blueberries, and strawberries—all of which contain antioxidants and are often labeled "superfoods." Is there any evidence that they can boost our brains? Certainly, many companies that market specialty drinks would like you to think so.

> Antioxidants are involved in helping brain cells get nutrients from the blood and in neuroplasticity. But they are best known for defusing the little bombs that result from normal chemical reactions—free radicals.

> Oxygen is the stuff of life, but too much of it can be toxic. While you can't breathe yourself to death, if you are getting oxygen from a supplemental source—for example, when scuba diving—you can take in too much oxygen, and that can ultimately cause problems, such as seizures.

> We need oxygen to extract energy from our food, a process that leaves behind metabolic byproducts such as free radicals. These are atoms that are electrically unstable; they have an unpaired electron. Because of this instability, free radicals can strip an electron from another molecule nearby. As they travel through the body, they can wreak havoc by creating more unstable molecules in their wake.

> This domino effect is how free radicals can damage cells, and too many free radicals in a person's body can become a problem. That's why the body has natural defenses to protect against the proliferation of these little bombs. Cells can keep free radicals penned in with physical boundaries. We have enzymes that

neutralize oxygen gone awry. Antioxidants from our diet can donate their electrons to stop the chain reaction.

- That's all part of the normal metabolic process. But the question at hand is whether more antioxidants will enhance brain function, or even protect it from decline.

- Studies in animal models do show some positive effects of adding antioxidants to the diet, but the data from human studies are mixed. Smaller studies have reported some effects, but once those studies are replicated with larger sample sizes, the effects tend to go away. This means that there are likely other variables affecting the results in the smaller samples.

- Studies have shown that taking too much of an antioxidant, such as vitamin E, can have negative side effects, such as an increased risk of prostate cancer.

VITAMINS

- In 1988, an influential placebo-controlled study of 12- to 13-year-olds showed an improvement in nonverbal IQ for those who took them. But since then, the evidence is building that adding vitamins to a healthy diet doesn't help the brain.

- Even so, research indicates that poor nutrition can harm cognitive function. So, for children who are in danger of not getting enough nutrients from their diet, vitamins are a good idea. For everyone else, it doesn't seem to make a measurable difference.

POWER DRINKS

- You might have seen bottles in your local health-food store of brain-boosting drinks, marketing better sleep, sharper wits, and less stress. Some of these even contain neurotransmitters and hormones.

- But these drinks are classified as dietary supplements, not food or drugs, so they don't need FDA approval, or even safety testing, to tout their benefits.

- There's not much evidence that you can drink your way to a better brain—unless your drink is laced with caffeine. It's difficult to say if coffee staves off disease yet, but coffee most likely does leave a person more alert and able to complete cognitive tasks and thus score higher on such measures. It probably does not prevent plaques and tangles, which are the pathological markers of Alzheimer's disease.

- Caffeine might have a protective effect, but it remains unclear whether it's a direct physiological mechanism, such as reducing inflammation, for example, or more related to increasing cognitive resources, such as helping you focus better on the task at hand.

- Though, again, this story is one of moderation. We do know that sleep deprivation can lead to increased Alzheimer pathology, so if too much caffeine is interfering with your sleep, that's not good.

CALORIC RESTRICTION

- There does seem to be some evidence that caloric restriction—eating substantially less than most people do—may enhance cognition and even extend your lifespan.

- In mouse models, restricting calories significantly, by having them fast every other day, has been shown to improve cognitive function and protect against Alzheimer's, Parkinson's, and Huntington's diseases and stroke.

- Fasting (while maintaining essential vitamins and other nutrients via supplements) can induce the growth of more new neurons, or neurogenesis, in mice. It can also positively affect their neuroplasticity—the physical changes that cells undergo during

learning—which might stave off age-related cognitive declines and restore function if the brain is injured.

- Even just delaying the next meal seems to enhance intelligence in mice, even when the ultimate calorie intake is the same. It seems that fasting can stimulate the production of certain proteins and hormones that improve function, such as BDNF.

- Evidence for the cognitive benefits of caloric restriction is plentiful among rodents. There's some encouraging evidence from studies involving humans and other primates, but the data here are mixed.

- One reason why we still don't know how caloric restriction affects primates is because our diets are so variable. Not enough food is bad for your brain, and too much unhealthy food is also bad for your brain. But we don't yet know whether restricting calories in total can keep your brain young.

EXERCISE

- Exercise does seem to reliably stave off cognitive decline, trigger the production of BDNF and other helpful proteins, and boost your brain. In humans, exercise increases BDNF, and that might be the mechanism by which it protects against neurodegenerative diseases.

- Consistent aerobic exercise increases the amount of gray matter in your brain, especially in the hippocampus and prefrontal cortex, which are responsible for memory and cognitive control.

SUGAR

- In 1995, a meta-analysis was designed to examine the effects of sugar on the behavior and cognition of children. By then, 23 studies had already been conducted to address the issue. When studies were carefully controlled for expectation effects, and measures were objective, consuming sugar had no effect on most children.

- Long-term studies do find negative effects of junk food on cognition. This has social implications, because children of lower socioeconomic status tend to consume more junk food. Indeed, the problem may not be about too much sugar but about malnutrition in general, because these same children are more likely to have little or no omega-3 fatty acids, for example, in their diets.

SMART PILLS

- Pills that enhance your brain—so-called nootropics, or "smart pills"—seem to be more and more commonly used by healthy people, and the billion-dollar industry that supplies them is blossoming.

- Most nootropics are stimulants that boost cognition essentially by staving off fatigue and thereby increasing mental focus. These include drugs such as Adderall and Ritalin (traditionally prescribed for the treatment of attention deficit hyperactivity disorder) and modafinil.

- Adderall, Ritalin, and modafinil are all controlled substances in the United States because of their high potential for abuse. They prevent brain cells from reabsorbing the neurotransmitters norepinephrine and dopamine, which leaves more of them available for use by the cells. They might seem harmless, but they do have side effects, including sleep problems, anxiety, headaches, dizziness, and an increased heart rate, among others.

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van de Rest, Geleijnse, Kok, and van Staveren, et al, “Effect of Fish Oil on Cognitive Performance in Older Subjects.”
Wolraich, Wilson, and White, “The Effect of Sugar on Behavior or Cognition in Children.”

QUESTIONS TO CONSIDER

1. Can your brain tell the difference between healthy food and junk food?

2. What effect might your gut microbiome have on your brain?

13

CAN BRAIN GAMES MAKE YOU SMARTER?

In the last few decades, we've gained a better understanding of how the brain changes with learning or other experiences and how even elderly brains are capable of growing new neurons. As a result, there's been a shift in how neuroscientists think about the brain—from imagining a complex but static machine to a living and malleable collection of circuits working together to provide us with a mind. This malleability, the changes that happen in the biology of the brain, is called neuroplasticity.

THE NUN STUDY

> There are times in your life when your brain is more plastic than others—in the first few years of life when all of those neurons are finding their connections. But what happens as we get older?

> For a long time, we thought that age went hand in hand with senility—that some people managed to stay cognitively sharp until old age but they were the exception. Most people were doomed to a long, slow decline, and there wasn't much we could do about it.

> Then, scientists stumbled on a perfect subject group, living in a setting for decades that was as close to a laboratory as one could imagine yet still "in the wild": nuns. In 1986, psychologists began a longitudinal study of cognitive function in a group of 678 Catholic nuns to find out if they could see early signs of Alzheimer's disease and predict who might contract the disease in old age.

- The nuns were relatively similar along a number of important variables that can affect one's risk of developing dementia: their home environment, no history of drug abuse, little or no alcohol, no pregnancies, and so on. And they were willing participants in all kinds of cognitive and physical tests, year after year.

- The nun study spearheaded the idea that we can stave off the symptoms of dementia, to a certain extent, by using our brains wisely. The more cognitive resources we have—which we build up over a lifetime of habits, not just from our genes or early experiences—the more protected we are from the consequences of neurodegenerative diseases.

- In addition to donating their time and bodies, the nuns also gave the scientists permission to analyze the mini-autobiographies they had to write in their 20s to get into the convent. The more ideas and positive emotions that the nuns packed into their sentences, the more likely they were to live to a ripe old age. In some cases, it seemed as though an active brain and a happy disposition at age 20 could tack on an extra 10 years at the other end of the lifespan.

MYTH

Playing games will make you smarter.

TRUTH

Brain-training games might make you better at playing games, but the evidence that any effect is transferred to activities of daily living or general intelligence is sparse.

BRAIN-TRAINING TOOLS

- It's one thing to note that people who age well and live long, productive lives share certain traits. But if those traits don't come naturally to you, can you adopt them and still enjoy the same benefits?

- Even more simply, can we improve our brain function, rather than simply stave off decline? The data answering this question are more mixed.

- Companies such as Lumosity, Cogmed, Posit Science, and others are selling brain-training tools designed to make you smarter, in many ways. The brain-training tools developed by these companies are video games that supposedly target cognitive skills such as working memory and executive function.

- People can pay a lot of money for these games and spend a lot of precious time playing them. But are they better for overall brain health than other ways of passing time, such as physical exercise or learning a new language?

- The companies and the scientists behind them will say yes. They argue that, just like building up specific muscle groups in your body, your brain needs specific types of exercises to show specific results.

- To assess the effectiveness of brain-training games, we need to think about the task in front of these companies: How can they develop games that are fun to play but that hone skills that their clients can transfer to the real world?

- Transfer comes in different forms, but where brain-training games are concerned, we want to know about near and far transfer. There's no doubt that by playing a video game for hours, you'll get better at playing that game, no matter how old you are, especially if the company selling the game programs it in such a way that you're always challenged, even as you get better at it.

- But will playing these games make you more likely to remember your entire grocery list, where you parked your car, or any other of the myriad tasks that aging seems to make more difficult?

- Here, we are talking about the difference between near transfer and far transfer. Near transfer refers to benefits that you might see in tasks that are very similar to the video game that you've been training on. Far transfer is the holy grail: Can playing a set of video games make you smarter in many different ways?

- In 2014, a group of 70 cognitive scientists and neuroscientists signed a white paper based out of Stanford University that came to the following conclusion: Many of the claims used to sell brain-training tools are exaggerated and misleading.

- Certainly, practicing a skill—whether it's playing the piano, speaking French, or training on a working-memory game—results in significant improvements on the practiced task. And sometimes, this improvement can spread to other similar skills.

- Some studies report enduring or lasting changes in these near-transfer effects, while others show that any gains dissipate over time. But the problem is that we haven't seen evidence of lasting or significant changes in a person's general cognitive function in daily life even with extensive brain training. In other words, we lack evidence that brain-training games produce any far-transfer benefits, including preventing dementia.

- What is exciting, though, is that we now have a significant body of evidence that even elderly individuals have the potential to learn new skills. We just don't see proof that learning these skills has a measurable impact on broader abilities that are relevant in the real world or that brain training promotes brain health in general. But there might be benefits in people who are at risk, for whom an active mental life can stave off signs of decline.

BRAIN-TRAINING STUDIES

- There are plenty of studies and companies that show positive effects of training on some measures of cognitive function. Their effect sizes are generally small to moderate, and there is still ongoing debate among neuroscientists about what these effects mean and whether they represent real evidence of change as a direct result of training.

> To evaluate whether the training itself built up cognitive resources or if there is another explanation, the way that the experiment is designed is of key importance.

> Scientists who conduct studies on brain-training games that contain a no-training control and a control group trained on a task that isn't thought to benefit the skill in question find a big difference between the training group and the no-training control and a somewhat smaller difference between the training group and the group that played a game that's not designed to, for example, improve attention or working memory or whatever they are testing.

> But if it's at all obvious to the participants that the games were supposed to make them focus better and the test is of how well

INVESTING IN BRAIN-TRAINING GAMES

Here are a few things to remember when deciding whether to invest time and money in a brain-training product:

1. Are you going to be devoting time to the training that you'd otherwise spend engaged in other activities that have been shown to have a positive benefit, such as socializing or learning something new? Or would you just be doing something passive, such as watching television, during that time anyway?
2. Are you basing your choice of training on the results of a single study with a fairly small sample size? If so, you might not see any far-transfer effects. But you might have a good time and feel better about yourself.
3. If you are at risk of developing a neurodegenerative disease such as Alzheimer's or Parkinson's, brain training is in no way a substitute for conventional medical treatments. No brain training has been shown to prevent these diseases or even slow their progression.
4. Like exercise, you can't just do 6 weeks of brain training and expect long-term benefits. You need to keep working out to see any positive and lasting effects.

they can focus, you might still see a difference in motivation, which might account at least for part of the effect. And there's some effect of motivation because the group playing a different game generally fares better than the no-training control group.

> You might also see a difference in strategy: Maybe the attention-training group learned not how to focus attention but how to "beat the test." Maybe this group is using a totally different strategy to complete the attention task. And this strategy change, in addition to the motivational factors, might explain the entire effect.

> The problem is that this strategy might be specific only to the type of attentional skill that is tested by the cognitive tests. It likely doesn't lead to a general improvement in attention or solve the problems that the person needs solved in terms of real-world applications.

> In neuroscience, we have to design tasks that are proxies for the real-world cognitive skills that we're interested in. But that doesn't mean that improvement on a single task will be a good proxy for general improvement in cognitive function. That's why we often use a battery of different tests when we are looking to assess general functioning, or even a specific ability.

> But brain-training companies don't have the same mandate: If they can sell a game on the basis of showing improvement on one cognitive test, they will do that. As consumers who will have to part with both time and money, you need to be more savvy and demand evidence that the changes they promise extend to situations in your life that you are seeking to improve.

> As brain-training games get more attention from the gaming industry and neuroscientists, they get better—and more fun. So, it's generally not a bad thing to spend some time playing them if you're enjoying yourself.

> You just need to evaluate the opportunity costs. Are you spending time on games that you would otherwise spend interacting with

others, learning a new language or musical instrument, or getting physical exercise? If so, that might not be the best decision if your general cognitive functioning is what you're worried about.

> There are many studies showing that people with strong social support networks, who are active learners, and who exercise fare better in terms of cognition than those who spend most of their time alone or doing passive activities or who are largely sedentary.

> Older adults who play brain-training games often report that they feel better about their minds and that they enjoy the games—which is great. A positive outlook can go a long way when it comes to longevity and healthy aging.

> But by some measures, self-reported improvements in cognitive function may be more akin to a placebo effect. Perhaps it doesn't matter so much exactly what kind of training you do, but the feeling that you're exerting some control over your cognitive functioning is what's really beneficial. The placebo effect isn't a bad thing, but it can be harmful if you are spending all your time in front of a computer instead of living your life to the fullest.

> And it can be even more pernicious if you become convinced that brain training can prevent neurodegenerative diseases such as Alzheimer's. There is no credible evidence that brain games of any kind can prevent or reverse the course of Alzheimer's.

EXERCISE

> Regular cardiovascular exercise can improve blood flow throughout your body, including your brain, which requires a lot of nutrients and oxygen. Exercise programs have been shown to significantly improve performance on tasks measuring attention, decision making, and some aspects of memory. They've also been shown to attenuate loss of cognitive function in people at risk for neurodegenerative diseases.

> In comparing physical exercise with brain training, the effect sizes are very similar. So, neuroscientists and clinicians will recommend exercise just as readily as the best-selling neuroscientist-designed brain-training game. Exercise can provide other benefits to the body that sitting in front of a screen does not, especially if exercising involves social interactions, too.

SUGGESTED READING

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Colzato, van den Wildenberg, Zmigrod, and Hommel, “Action Video Gaming and Cognitive Control.”

Karbach and Verhaeghen, “Making Working Memory Work.”

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Roig, Nordbrandt, Geertsen, and Nielsen, “The Effects of Cardiovascular Exercise on Human Memory.”

QUESTIONS TO CONSIDER

1. What kinds of skills would you like to hone? How might they affect other aspects of your cognitive functioning?

2. What other benefits does lifelong learning offer?

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DOES YOUR BRAIN SHUT DOWN DURING SLEEP?

Sleep is one of the most mysterious behaviors known to man—and virtually the entire animal kingdom. Most people think of sleep as a time to rest our weary bodies, but the more we study it, the more we realize that sleep is really about the brain, and it's not at all a restful or passive process. The idea that sleep is designed to give our brains a break is a myth.

WHAT IS SLEEP?

> In the 1950s, the idea that sleep puts the brain to rest was blown away by the discovery of just how active our brains are when we're deep in sleep. We don't just go into a hibernating state and shut down our brains; instead, during sleep, our brain activity follows a cyclical pattern, alternating between different brain states, each a unique stage of sleep, likely having a specific set of functions.

> We can roughly divide sleep into 3 major categories: falling asleep and being lightly asleep (stages 1 and 2); deep sleep, characterized by slow brain waves (stages 3 and 4); and rapid eye movement (REM) sleep, during which our brain activity looks a lot more like it does when we're awake, with some critical differences, and our eyes dart around under our eyelids.

> Each stage can be distinguished from the others by way of muscle and brain activity, and even in terms of the effects on us if we're deprived of one stage or another.

- The relative proportion of time that you spend in non-REM and REM sleep changes throughout the night. At first, we spend more time deep in non-REM sleep, and as the night wears on, our cycles include more time in REM and lighter stages of non-REM sleep.

- REM sleep has been observed in every terrestrial mammal whose sleep we've studied, and every one of these mammals alternates during sleep between periods of REM and non-REM behavior.

- In terms of brain activity, what seems to be very different between awake and asleep states is the degree to which neural activity, the firing of individual neurons, is in sync. Most of the time, when we're awake and using our brains, our neurons send signals to each other but act relatively independently.

- When you're engaged in non-REM sleep, your brain is idling like a car in the sense that the neurons, which were working hard during the day to get things done, now fall into a cyclical synchronous pattern of firing.

- When we measure this activity, we can get bigger signals during sleep than during awake states, but that's because there are more cells working together when we're sleeping, not because the cells themselves are more active.

- In fact, most of the cells are less active in non-REM sleep. This is especially true of the cells in the brainstem, the part of the brain that is responsible for keeping you alive by monitoring your basic functions. In the cortex, where much of your higher-order thinking happens, the cells are less active, too, but only slightly less so.

MYTH

When you sleep, your brain rests.

TRUTH

Your brain is very active during sleep—but in a very different way than it is when you're awake.

- But there are cells whose bursts of firing signal the beginning of deep, or slow-wave, sleep. And there are cells that, in contrast to virtually all other brain cells, are more active during sleep than during waking. These cells are tasked with the responsibility of putting you and keeping you in a sleep state.

- The patterns of brain activity during REM sleep, however, are more like waking than non-REM sleep. Cells take on their individuality once again, and there is less synchrony between ensembles of neurons in terms of their firing patterns. And our brains use just as much fuel during REM sleep as they do when we're awake.

- Although there is an increase in activity in some regions of the cortex compared with non-REM sleep, there are a few key regions in REM sleep where activity is significantly attenuated, even compared with waking.

- One of these regions is the dorsolateral prefrontal cortex, the part of our brain that is responsible for keeping our social behavior in check and making thoughtful, rational decisions, among other things. Along with other regions involved in self-monitoring and attentional focus, this part of the brain practically shuts down during REM.

- Just like cells that change their firing patterns to put us into deep sleep, there are cells whose job it is to turn on REM sleep. Vivid dreams are most often reported when we wake people up out of REM sleep, though dreaming is not exclusive to REM, as is often thought. We do dream during non-REM sleep, but overall, it seems as though we remember our REM dreams more strongly than non-REM dreaming.

- The parts of the brain that control and activate our muscles and joints are engaged during REM sleep. But luckily the brain has adapted ways of ensuring that we don't act out our dreams, for the most part.

SLEEP DEPRIVATION

- The answer to the question of why we sleep remains one of the great scientific mysteries. But we've got a few good hunches and some evidence to support each one. We sleep for many reasons, with benefits to many different aspects of our bodies and minds. But we can draw some general principles from the research that has thus far been undertaken.

- We have to decide how we want to approach the problem: Do we want to infer the purpose of sleep from what happens when we don't get enough of it, or do we want to compare our sleep patterns with other animals to see if we can find meaningful differences? Each of these approaches yields slightly different answers, but there are places where the theories of why we sleep converge.

- First, what happens when we don't get enough sleep? It's not a pretty picture. In fact, extreme sleep deprivation can kill you. Sufferers of a rare genetic condition called fatal familial insomnia die within months of symptom onset.

- Sleep deprivation is so aversive that it is used as an interrogation technique and might be considered torture. Even seemingly innocuous sleep deprivation can have profound effects on our bodies.

- As we get older, our brains have a harder time putting us to sleep and keeping us asleep, and some people think that they just need less sleep as they get older—because they sleep less anyway. But the truth is that it's almost more important to get adequate sleep in our twilight years, because that's when sleep deprivation can have truly devastating consequences, including increasing the risk that a person develops Alzheimer's disease.

- Attention is affected even with minimal disruptions of sleep. Some people argue that this is one way your brain can get you to make up your sleep debt; if you can't focus on anything else and there's a strong drive to sleep, then maybe you'll decide to curl up and take a nap to put your brain back into working order.

- We also see impairments in decision making and tend to have less willpower without sleep. We're more likely to make the impulsive choice that gives us an immediate reward rather than thinking about how our actions will affect us in the long term.

- It can be harder for us to recognize emotions in other people, and we respond more readily to negative stimuli. Some people become more anxious.

- All of these different effects of sleep deprivation tell us that there may be many different reasons why we sleep: metabolic, cognitive, emotional, and so on.

> But paradoxically, sleep deprivation can also lift your mood, causing a temporary mild euphoria. It's even used to treat some people with depression. And this might be related to the major changes in the types of neurotransmitters that are released during sleep versus wakefulness.

> The long-term effects of sleep deprivation are by no means desirable, particularly when it comes to memory, which can be roughly divided into short-term, or working, memory and long-term memory, if we're thinking about how long we want to hold onto the information that we're learning.

> Long-term memory can then be divided into 2 major categories: declarative memory for learning new facts and remembering experiences consciously, and non-declarative memory, which doesn't involve consciousness in the same way, such as skill and habit learning, conditioning, and making implicit associations.

> When it comes to sleep, different stages of sleep seem to have different effects on these different memory types. At the outset, we need sleep to clear our minds and prepare us for the next day's learning. We need to be able to pay attention to the right things, and we need to have our hippocampus and prefrontal cortex in particular firing on all cylinders, not sluggish and less active, as we see when we're sleep deprived.

> After learning, sleep plays another set of roles, depending on the stage of sleep and the type of memory that we're laying down.

> When it comes to our declarative memory, it seems that both REM and slow-wave, or non-REM, sleep play important roles. In many studies, scientists have observed that the neural firing patterns present during the learning phase are replayed during sleep, strengthening the connections between the neurons that represent these newly formed memories.

- The more of this replay scientists have observed, particularly during slow-wave sleep, the better the performance of the subjects on tests of the memory the following day. And, after a good night's sleep, these nascent memories are less affected by interference than they were on the previous day.

- When it comes to skills and habits, though, it seems that a different pattern of brain activity during sleep is the key. Early in the night, when we're spending more time in slow-wave sleep, our declarative memories are being pruned and strengthened, leaving us with stronger memory traces for the things that we really want to remember and not the irrelevant items.

- Then, there seems to be a shift in the type of memory that is enhanced with sleep later in the night, when we spend more time in shallower non-REM sleep and in REM sleep. It seems that the type of neural firing pattern that is present during this part of the night is particularly effective at strengthening connections between neurons in the parts of the brain that are involved in skill and habit learning, called procedural memory.

COMPARATIVE BIOLOGY

- We can also use comparative biology to make inferences about the purpose of sleep because different animal species have vastly different sleep patterns. Some animals spend most of their time asleep; others barely sleep at all. What predicts the amount and type of sleep that a species engages in?

- In this case, it seems as though size matters. In general, the larger the animal, the less sleep it seems to need. To explain this, there seems to be a correlation between metabolism and sleep needs. The faster a species burns through energy stores, the more sleep it needs to restore a balance.

> Diet matters, too: Carnivores sleep longer than omnivores, who in turn sleep longer than herbivores, who need to eat more frequently to keep up their fuel stores. The reactions needed for metabolism create by-products, some of which can be toxic. One thing that happens during sleep is an increase in cerebrospinal fluid, the protective liquid that our brains float in.

> Perhaps this increase acts like a waste management system, washing away toxic by-products of metabolism and sprucing up the brain for the next day's work. More metabolism during the day means more work for the waste disposal team at night.

> And there's some solid evidence for this function of sleep. We used to think that brain cells got rid of their garbage by recycling it, and when cells became less efficient at recycling, certain by-products of chemical reactions began to build up in the brain. One of these by-products is beta-amyloid, the buildup of which seems to lead to the development of Alzheimer's disease.

> But not everyone bought into the recycling idea. In particular, Maiken Nedergaard, a scientist at the University of Rochester, discovered that sleep plays a critical role in cleaning up the brain's undesirables.

> Perhaps when we don't give our brains enough time to dispose of the unnecessary waste, the buildup of nasty proteins that are associated with neurodegenerative diseases becomes a real problem. There is a strong relationship between disordered sleep and neurodegenerative diseases; we just don't know which is the cause and which is the effect. If we can enhance the sanitation engineering in a brain at risk for neurodegeneration, perhaps we can reverse the course of the disease—or even prevent it from developing altogether.

SUGGESTED READING

Goldstein and Walker, "The Role of Sleep in Emotional Brain Function."
Siegel, "Why We Sleep."
Walker, "A Refined Model of Sleep and the Time Course of Memory Formation."

QUESTIONS TO CONSIDER

1. Sleep is not only important for consolidating the previous day's information but also preparing your brain for the next day. How does sleep deprivation affect your cognitive function?

2. Why, in terms of what's happening in your brain, do you think the advice "go sleep on it" is helpful?

15

ARE YOUR DECISIONS RATIONAL?

We tend to think that rationality is what drives our big decisions—that we only make an important decision after carefully evaluating our options and weighing all the pros and cons. But the relatively new science of behavioral economics, coupled with decades of psychology research, is poking fairly large holes in this myth. The truth is that we are not only largely irrational in how we decide, but predictably so.

RATIONALITY

> Standard economic theory is based on the assumption that human beings are guided by rationality: If there's a big demand for a scarce resource, people will pay a higher price for it than if there is no demand or if the resource is plentiful. If we need to make a change—whether with respect to a job, a house, or a partner—we will make a mental list of pros and cons and add them together, and the result of that computation will guide our decision making.

> If we screw up and do something irrational, such as pay too high a price for something easily acquirable, we'll figure that out fairly quickly, and the market overall, made up of millions or billions of rational beings, will correct the mistake.

> But standard economic theory fails to explain what marketing experts take for granted: We are often swayed in our decision making by things that any truly rational being would ignore.

- Williams-Sonoma mastered a strategy called the decoy effect ever since they first started selling bread makers that no one knew they wanted. At first, with only one option on the floor, sales were dismal. But by adding a premium version, sporting a bigger size and price tag to match, the original bread maker sold like gangbusters.

- The decoy effect flies in the face of rational models of decision making. Why should the introduction of a higher-priced option lead us to choose a product that we might otherwise pass on? Shouldn't our decision be based on an assessment of what we really need? And wouldn't we reasonably choose the item that meets that need for the lowest price?

- Contrary to what might be expected, the decoy effect is just as powerful in real estate and dating markets as it is in the small kitchen appliances market.

- The first principle of our predictably irrational decision making is that everything is relative and influenced by context. When choosing from alternatives, we can't help but make comparisons between options that are put in front of us—often to our detriment.

- This tendency is not just a guiding force in how we make choices; it's a guiding principle of brain function. Our brains are primed to look for change—for differences—and for patterns. Context affects both our attention and our perceptions.

- Think about being the lowest paid employee in the office. That can leave you dissatisfied. But transfer that exact same job and salary to a company in which you're the highest paid and you'll experience an instant boost in happiness.

- So, like it or not, our brains are wired to make highly contextualized comparisons. Even our senses habituate to what stays the same but make note of what changes. This impulse to make comparisons

can lead us down the wrong path time and time again with respect to how we make decisions.

> **MYTH**
>
> You make rational decisions.
>
> **TRUTH**
>
> Most of our thoughts are dominated by self-talk, and our conscious mind is not privy to many of the processes that lead to our decisions.

- Just as our senses can't register every aspect of the environment, our decisions are guided only by the information we can hold in mind—which is limited. When we can organize and categorize information easily, by comparing similar features, for example, we feel as though we can then make a good decision.

- The relativity principle explains why we don't hesitate to pay an extra few thousand dollars for a new paint job when we're in the midst of purchasing a house but balk at the expense once the purchase is in the distant past. After all, what's an extra $3000 when we're thinking about $300,000?

- This principle also explains why we'll drive across town to save a few cents on gas, knowing that it's cheaper over there, but spend $4 on a latte close to home without blinking.

TYPES OF THINKING

- The principle of relativity also shows us that we can categorize many things that our brains do into 2 types: fast and slow. Nobel Prize winner Daniel Kahneman calls these 2 types of thinking system 1 and system 2.

- Our fast-thinking brain influences our behavior in many ways: It searches for patterns, looks for confirming evidence, and fills in perceptual details when they are missing. It's effortless and automatic, and it's swayed by emotions. For many people, the fast-thinking brain is a stranger, whereas the slow, deliberate,

thoughtful brain is an old friend. That's what we think is our logical side.

> But, as Kahneman notes, what we are conscious of is the end product of thinking, not the thinking itself. That's even true when it comes to system 2, or our slow-thinking brain, though in that case, we might be able to control some aspects of it. The truth is that our slow thinker is heavily influenced by its fast-thinking counterpart, often without our knowledge, as the decoy effect clearly demonstrates.

> As Daniel Kahneman describes these 2 modes of thinking, the fast mode is subconscious and therefore effortless, feels automatic because we don't have a sense of control over it, is the major driver of our behavior, and is predictable. It also underlies a number of our cognitive quirks, such as stereotyping.

> The slow mode is less frequently used because it demands attention and effort. It's relatively logical and calculating, and it's conscious. But it's also lazy. Rather, our brains are lazy, often favoring the easy solution in favor of deliberate thoughtfulness.

> Your slow-thinking mode does the minimum required work to come to a plausible solution. And it's not just lazy thinkers in general that fall prey to the temptation. Most people are overconfident in their thinking. That's a thematic principle of our brain function that returns time and time again.

> We can't really control how much mental energy we put into different types of tasks; some tasks will draw more of our available attention and others will draw less. The amount of attention they draw depends on how skilled we are in the task.

> At first, driving demands all of our available mental effort—system 2 taxed to the max. Over time, we become more practiced at it, and many of its actions become automatized. Now they can be accomplished without much conscious thought, having become

integrated into system 1, and therefore we need less attention to accomplish the same thing.

> This is where things become dangerous, as we sometimes overestimate how little attention we need to pay to the road and indulge in the temptation to distract our minds while driving.

> Mental effort is expensive, so our tendency is to minimize it. As Kahneman puts it, laziness is built deep into our nature.

> Dan Ariely is no stranger to the social costs of this laziness. Many of his studies have shown that when our minds are preoccupied, or our mental capacity is altered by our emotional state or another physiological state (sexual arousal or hunger, for example), we're less likely to take the moral high road. We're more likely to succumb to discriminatory behaviors, to make superficial

judgments, and to behave primitively rather than as the civilized beings that we think we are.

> Decisions that we think we make rationally are influenced by our emotional and physiological states. We think that system 2 is in charge most of the time, but what we don't realize is that system 1 is always taking over when we're not paying close attention. System 1 might even drive system 2 outside of our conscious awareness.

> Our 2 modes of thinking leave us with 2 different selves: the self that is experiencing the world in the moment and the self that can reflect on the past. For most people, these 2 selves are so intertwined that they don't even know that both exist.

> But a set of studies by Kahneman and his colleagues have demonstrated this profound and enigmatic feature of human nature and that this feature can affect our decision making in wide-reaching and surprising ways.

> Think about a time when you were thoroughly enjoying an activity—for example, a night at the opera or an intense sports match—only to have the experience ruined by a bad ending. Maybe the soprano missed her high note or your team lost the game thanks to an inappropriate call by the referee.

> So often we get much more upset when such a thing happens at the end rather than sometime in the middle of the experience. And even though we spent the vast majority of the time enjoying ourselves, that last bad taste lingers on with us and tarnishes the whole memory of the event.

> But of course it didn't—that's completely irrational. It was just those last few moments that were ruined, not the rest of the time. But because we tend to remember endings more strongly than other parts of the experience, our remembering self ruminates and

categorizes the event as negative overall, neglecting the fact that our experiencing self was having a blast for the most part.

> There are now several studies showing that our ratings of enjoyment of an activity reflect a weighted average of the most intense moment during the event and of the end of the experience. It's called the peak/end rule, and it applies both to positive and negative experiences. And it influences the decisions we make about how we want to have those experiences in the future.

> Could the peak/end rule offer a solution to the age-old problem: should we rip off that band aid, causing a short but intense bit of pain or peel it away slowing, prolonging the suffering but limiting its intensity.

> The remembering self is illogical and misguided, but for the vast majority of people, it influences the decisions they make about how to spend their time and money much more than their experiencing self.

> Our remembering self is largely built over time by system 2, or our slow-thinking mode—the one that we think is responsible for our decisions, the big ones at least. But our fast mode influences this construction every step of the way, from choosing what we focus on to providing shortcuts in the form of heuristics and biases. So, we can't discount its influence on the ultimate choice.

> Duration gets compacted because what captures our attention and therefore is stored in memory are moments of change—the peaks and the ends (and, to some extent, the beginnings, too). But what happens in the middle is largely forgotten.

> Just like our senses, habituating to what's constant in the environment, our thinking systems are influenced by change. We make comparisons between things presented at the same time because that's about all that system 2 can handle. It's lazy, and

it's easier to compare 2 similar things and figure out which one is better than compare 2 dissimilar things.

SUGGESTED READING

Ariely and Wertenbroch, "Procrastination, Deadlines, and Performance."
Gino, Ayal, and Ariely, "Contagion and Differentiation in Unethical Behavior."
Lee, Frederick, and Ariely, "Try It, You'll Like It."

QUESTIONS TO CONSIDER

1. If we're all prone to comparisons, which option is better: buying the best house in a not-so-great neighborhood or the smallest house in the posh community? What would you do?

2. Now that you know how your brain can be both fast, automatic, and intuitive; and slow, deliberate, and lazy, how should you approach major life decisions?

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ARE YOU ALWAYS CONSCIOUS WHILE AWAKE?

Most people think of consciousness as binary—that you're either conscious or you're not. But the truth is that you can be in any one of multiple states of consciousness, from drowsy but aware to fully focused on your inner thoughts. In the brain, there are multiple streams of thinking that are going on at any given time, but somehow the brain pulls these together, integrating and binding them into a holistic experience.

CONSCIOUSNESS AND OUR BRAIN

> We experience our consciousness as a unitary experience, and we often think about it in terms of black and white—on or off, awake or asleep. But the truth is that we can be conscious at different levels; it's a continuum rather than a discrete condition.

> We know this because we can manipulate consciousness with psychoactive drugs and anesthesia. We might not know how consciousness works from the perspective of the brain, but we can alter it in fairly specific ways.

> We can, for example, inject drugs into our brains that hyperpolarize our neurons—change their electrical potential in such a way that it's much more difficult for them to fire in response to stimulation. Many of these drugs induce electrical activity that looks like what we see during non-REM sleep, so we might say that this anesthetic drug has brought about a less conscious or even unconscious state.

> But how do we know that a person injected with anesthesia is indeed unconscious? When anesthetics were first introduced, more than a century and a half ago, unconsciousness was defined behaviorally: If a patient is unresponsive, he or she is unconscious. But we now know that a person can be completely paralyzed and unable to respond but still remain conscious, called locked-in syndrome.

> Unresponsiveness is not sufficient to demonstrate unconsciousness. There are documented cases of patients responding to commands during surgery but waking up with no recollection of having been conscious. So, memory isn't good enough, either.

> Is there any particular brain region that resembles a switch? Probably the closest thing we have to a switch—when it's active, we're conscious, and when it's deactivated, we're not—is the thalamus, a relay center in the middle of the brain through which all sensory information travels (except smell) and that connects to many other regions of the brain, including our memory centers and frontal lobes.

> Damage to this part of the brain can cause a patient to enter a vegetative state. Recovery from such a state happens when the connections between the thalamus and parts of the frontal cortex are restored.

> When the thalamus stops working, loss of consciousness is not immediate. And while we see immediate changes in the electroencephalogram (EEG) signal when a patient becomes unconscious, the signal change in the thalamus can lag up to 10 minutes behind.

> Maybe, then, the thalamus is more like a central train station than an on-off switch: When the station is closed, information can't get through, but closing the station doesn't immediately stop the city from functioning.

> While the thalamus might play a central role in mediating conscious states, there are other regions, lower down the brain stem, that are also important and perhaps even more vital for cortical arousal.

THEORIES OF CONSCIOUSNESS

> There is a growing body of evidence suggesting that cortical arousal and consciousness are not the same thing. You can imagine an animal that is fully awake yet not necessarily conscious—simply reactive, in a reflexive way—and that the integrative functions of central regions such as the thalamus are necessary for consciousness.

> Indeed, in one of the main theories of consciousness, information integration plays a key role. Inspired by work on anesthetized patients, neuroscientist Giulio Tononi has proposed that we think about consciousness as having 2 main qualities: It contains information about an experience (you see a red car), and that experience is integrated (you can't not see that the car is both a car and red at the same time). Tononi suggests that this integration is a key part of consciousness; it's a part of the subjective experience.

> With this type of definition, then, a brain must have functional connections between key brain regions to be conscious. Indeed, when we see brain activation in a person that looks like a series of isolated islands rather than a connected network, consciousness has been disrupted.

> How do we experience our consciousness as integrated when different parts of our brains process different aspects of our experiences? Is our consciousness really integrated? Can we have multiple consciousnesses? Some neuroscientists think that we can, and they point to patients who experience multiple personalities as clinching evidence.

> Perhaps the most compelling philosophical theory of consciousness proposes that there isn't a single conscious entity in our minds but an endless stream of drafts. According to this view, different networks and pathways within the body and brain are constantly providing simultaneous but distinct information streams concerning the world.

> Each of these streams is like a separate draft of reality. And consciousness is not some single authoritative region in the brain that pulls all these drafts together into a unitary, authoritative, "true" experience. Rather, consciousness is precisely the multiple drafts themselves—all those separate streams of information happening at the same time.

> This multiple drafts model is the brainchild of American philosopher Daniel Dennett. According to this model, when we're not actually contemplating our own consciousness, we don't know if we are conscious and in what ways.

MYTH

Consciousness comes in 2 states: Either we are conscious or not.

TRUTH

Consciousness is a continuum with many levels that we can alter in many different ways, and animals can also be conscious in ways that might surprise you.

> Dennett argues that when we ask ourselves if we are conscious, our minds build up a stream of consciousness that gives us just that experience. The illusion of a unified consciousness is created. As soon as we think about something else, the experience of having a unified self fades into the background and our brain can get back to the important job of experiencing life.

BRAIN DAMAGE

> People with profound amnesia can't create the illusion of a coherent, continuous self because they have no memories to draw upon. But would we call them unconscious? What about patients whose memories are intact but whose attention is fragmented?

> Perhaps our consciousness is just a neural afterthought, as many neuroscientists suggest. Perhaps it is just one draft that our minds create and discard as another set of drafts are written in parallel. When lower-level perceptual processes go awry—when we have something in our eyes or can't hear quite well—the upstream cognitive processes notice, and we become conscious of the lack of information. But when the upstream processes go awry, we remain unaware of what we can't do.

> The paradoxical disconnect between what we can actually experience and what we are conscious of experiencing is present

in patients who have blindsight, a condition in which a patient has a lesion in the visual cortex and cannot perceive one part of his or her visual field. The damage isn't in the retina, so the brain has access to the primary sensory input, but visual processing breaks down later in the stream between sensation and perception.

> There are also documented cases of deaf hearing, blind smell, and numbsense, in which patients report no conscious experience of a certain sense but behave as though they can hear, smell, or feel just fine.

> These types of patients seem like the ideal candidates to solve the problem of consciousness—because they have vision, hearing, smell, or touch without the accompanying qualia or subjective experience of consciousness. This suggests that the subjective experience is real (because we can observe the lack of it) and that it has a neural basis (whatever part of the brain is damaged in the patients).

> But patients with these conditions still have other conscious experiences. They still feel as though they are conscious and that their inner selves are unitary. And their ability to perceive the world through their damaged sense is nowhere near "normal."

> In their daily activities, they don't use their "blind" sense. They generally can't recognize familiar objects without prompting, for example. And they are not completely blind in terms of their conscious experience of seeing: They can sometimes consciously see high-contrast moving objects, for example.

> One patient, for instance, would report seeing fast moving objects but not slowly moving ones. What does his damage tell us about the conscious experience of seeing? Are fast and slowly moving objects consciously recognized in different parts of the brain? What happens when we compare these patients to patients who can't see motion at all?

- We still come back to the problem of finding a neural correlate for the subjective experience. We know that vision is modular—that we process different aspects of the visual world in different brain regions but our experience is coherent. Does that mean that the neural basis of consciousness might also be modular, but still give us the illusion of coherence? Once again, Dennett's multiple drafts model seems best suited to fit the data.

- For many people, even though the theory of multiple drafts accounts for much of the evidence, it still doesn't seem to characterize our experience. It doesn't seem to capture what many people feel is the core, essence, and true power of consciousness: to bind together our experiences into one self.

- Even Kahneman's distinction between our 2 selves—the one that experiences the world and the one that remembers it—doesn't shatter this illusion completely. We can still accept that our remembering self might not be an accurate record of our experiencing self without throwing away the notion of the self altogether, as Dennett seems to ask us to do.

- And this illusion of the unified self is so strong that for many people, the idea that our consciousness can supersede our biology—that some aspect of our minds persists even as our bodies die—is a given.

NEAR-DEATH AND OUT-OF-BODY EXPERIENCES

- Near-death experiences are often hailed as evidence for the idea that consciousness is distinct from the physical processes of brain and body. The related out-of-body experience, in which the person feels as though he or she had left his or her body and is observing it from a different point of view, can be so compelling to the person undergoing it that there is almost nothing that can convince him or her that it was just a figment of his or her physical brain.

- Skeptics and believers alike point to the uniformity of a near-death experience as supportive of the notion either that there is life after death or that the experience is simply the product of disordered brain function.

- Feeling as though you are dead is not limited to near-death experiences. There is a strange delusion called Cotard's syndrome in which the sufferer believes that he or she is dead. These patients will repeatedly insist that they are dead, and in heaven or purgatory, and will tell you the manner of their death. Causes of the delusion vary from typhoid to multiple sclerosis and with damage located in the parietal and prefrontal cortices.

- Out-of-body experiences are also called autoscopic because the illusion involves the sensation that you are floating outside of your body and that you can see your body from above.

- Out-of-body experiences are also not limited to near-death experiences as people report having them just before they fall asleep or when they have sleep paralysis—when their conscious mind wakes up before the body has had a chance to clear the nervous system of the neurotransmitters that inhibit muscle activity during REM sleep.

- In one study, out-of-body experiences were induced by stimulating a specific part of the brain called the temporoparietal junction.

- The experience of moving down a tunnel can also be induced in other ways. Most neuroscientists agree that tunnel vision can occur when the eyes aren't receiving enough oxygen from the bloodstream, a condition known as anoxia. Anoxia is a common feature of many situations in which near-death experiences occur.

- When it comes to the types of people and scenes patients encounter on their trips to death's door, there is a strong correlation between their cultural or religious beliefs and what they report seeing.

> The feeling of being in the presence of someone else can also be induced with electrical stimulation to a part of the brain called the angular gyrus, as has been noted in patients with epilepsy who are undergoing surgical treatments. When the surgeons stimulated this region, the patient reported feeling someone else in the room.

> While we haven't yet discovered a pattern of brain activity that is common across all near-death experiences, each of the separate features can be explained by neurophysiological changes.

SUGGESTED READING

Alkire, Hudetz, and Tononi, "Consciousness and Anesthesia."
Mobbs and Watt, "There Is Nothing Paranormal about Near-Death Experiences."
Tononi and Koch, "Consciousness."

QUESTIONS TO CONSIDER

1. Dennett's multiple drafts model of consciousness opens the door to the possibility that we all have multiple selves, each corresponding to a different set of drafts. How do we keep a sense of a unified self intact, then?

2. What do patients with amnesia show us about our own consciousness?

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ARE OTHER ANIMALS CONSCIOUS?

Most people argue that animals aren't conscious to the same extent that we are. But we can't even figure out human consciousness, so how can we be sure that animals aren't conscious? Even complex, purportedly uniquely human traits, such as self-recognition, can be observed in other animals. Consciousness is a continuum, and the simplest explanation for its existence in humans is that it evolved in small steps, just like the rest of our bodies. If it did, then we can see precursors of ourselves in animals. If we're conscious, then likely many of them are, too—though perhaps not in exactly the same way.

VIOLENCE

> Primatologist and neuroscientist Robert Sapolsky divides human traits or behaviors into 3 categories: behaviors shared by other species, behaviors for which we have the same tools as other species but use them in a novel way, and behaviors that have yet to be found in other creatures. The last category is in many ways the most difficult to be sure of because so often what seems to be unique to humans gets discovered, through careful experimentation, in other animals. But that's the beauty of science: When we ask the right questions, we learn more than we set out to.

> Take the issue of violent behavior, for example. Nature can be mercilessly mean. But science has helped illuminate the

continuities between some of the less savory aspects of human and animal behavior.

> Human beings can be incredibly cruel to one another, let alone to other creatures with whom we share the earth. But there are other species who practice genocide, infanticide, siblicide, and other forms of intentional killing. Eagles throw mountain goats off of cliffs to kill them. Many large predators begin eating their prey before they have had time to die.

> You might argue that these incidents involve animals killing for food—simply survival of the fittest, rather than actual senseless cruelty, designed only to cause suffering. But lions will kill cheetah cubs or other rival predators with whom they are unrelated and not eat them afterward. There are other species who cause suffering to members of their own groups, such as ants who will kill another colony.

> Most if not all examples of violence in the animal world have been explained in terms of a fight over scarce resources. Infanticide, for example, seems to be about access to females, who, newly without offspring, are more likely to mate and breed with the victor.

> Most people can stomach violence between members of other species, even primates, because we imagine that the animals can't empathize with their enemies and don't understand that another being might suffer. They don't feel compassion, we might say.

EMPATHY AND COMPASSION

> Is it true that compassion is uniquely human? Is psychological suffering unique to us, too? In other words, do other animals feel social pain the way we do when we see a beloved friend or family member suffer and die?

> What kind of consciousness would be necessary to feel social pain? First, one would have to have developed a sense of self—some sort of coherent identity that is separable from others.

> In human infants, this sense seems to develop sometime in the second year of life, when toddlers begin to understand that what goes on inside their heads isn't obvious to those around them. Until they gain this understanding, we think that they operate with the belief that consciousness is collective—that we all share one mind.

> Developmental psychologists have used a number of clever ways to assess the emergence of self-identity. They observe that toddlers begin to use the pronouns "I" and "you" around this time. Then, they begin to recognize themselves in mirrors.

MYTH

Animals aren't conscious.

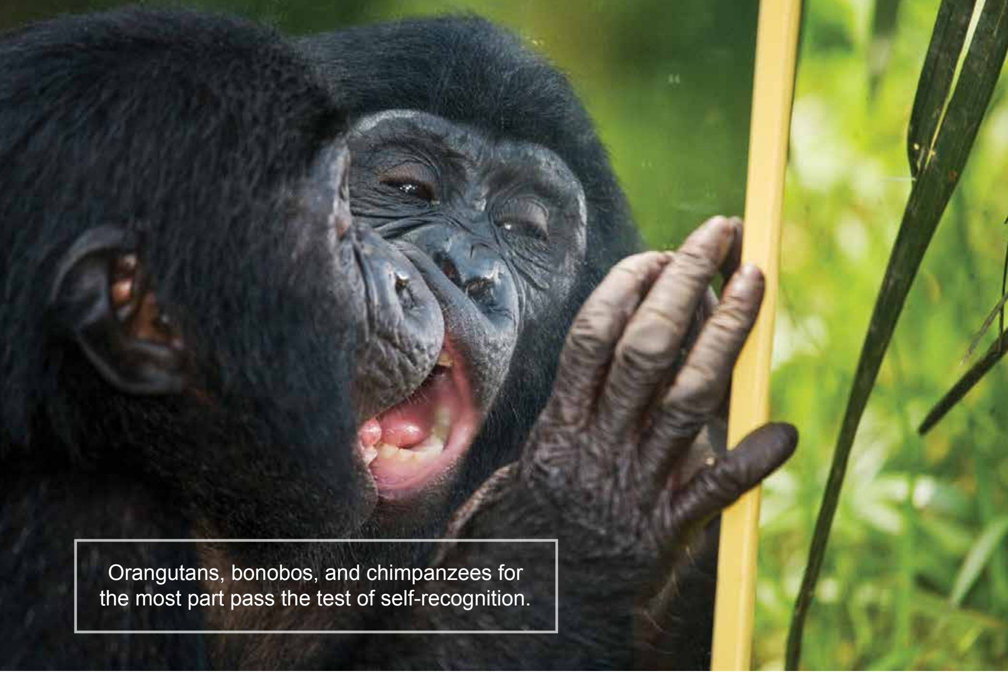
TRUTH

The brains of animals are remarkably complicated, and they are much more similar to our brains than many people think.

> In fact, the mirror test, which involves whether an animal can tell that its own image is being reflected back to it or whether it treats the animal in the mirror as another, is the classic test of self-recognition in other species.

> Gordon Gallup is credited with having devised a version of the mirror test that has now become famous. He gave young chimpanzees a mirror to play with and noticed that they began to use it as an instrument to gaze at parts of their bodies that they could not otherwise see, such as the inside of their mouths.

> But he wasn't sure that the animals could tell that the chimp in the mirror was itself, so he anesthetized them and then drew red marks on their faces. When they woke up, they immediately tried to rub off the mark from their own faces, and not the image in the



Orangutans, bonobos, and chimpanzees for the most part pass the test of self-recognition.

mirror, demonstrating that they understood that the mirror was a reflection of themselves.

- Since then, this test has been used to evaluate self-recognition in many other species, including toddlers, who generally fail until sometime around 18 months. Orangutans, bonobos, and chimpanzees for the most part pass the test. Some elephants, dolphins, killer whales, and even possibly magpies have passed the mirror test.

- Although dogs and cats fail the test, it's possible that they fail not because they don't have a sense of self, but because they don't use their senses the way that we do. Dogs, for example, can't see very well, so perhaps they would recognize themselves via smell, rather than sight.

- While we can't use the mirror test conclusively to rule out self-recognition in some species, there is enough compelling evidence

to conclude that we're not the only ones with a sense of self, although some psychologists reject this evidence and claim that self awareness remains unique to humans.

> The next step in developing empathy is to recognize that your own thoughts, feelings, and beliefs might differ from those around you. Psychologists call this ability having a theory of mind: developing an understanding that other people also have a sense of self with hopes, fears, and wants.

> Deception is one way in which psychologists can assess the development of theory of mind in both children and other species. Many insects can camouflage themselves or have evolved patterns of markings to deceive their prey. Other insects can fake an injury to distract their predators. But these examples are written in their DNA and are expressed without the animal's intent to deceive.

> Monkeys will refrain from announcing that they have discovered a food source if the food is particularly tasty. They will wait until their peers are distracted before engaging in some kind of taboo behavior, knowing that were they to be observed there might be social consequences.

> There are many studies demonstrating repeated failures of many animal species to demonstrate theory of mind. When we test animals through our human lens, assuming that they see the world much as we do, we are easily convinced that they are cognitively simpler than we are.

> Many experimental designs fail to capture the fact that we might not be able to look inside the minds of other animals as effectively as members of the same species.

> Evaluating empathy even in our own species is a major challenge. A behavioral test of empathy that doesn't rely on self-report does not seem to exist yet. In addition, even demonstrating empathy—

the ability to put yourself in someone else's shoes, to feel what he or she feels—might not be enough to capture what is one of humanity's greatest virtues: compassion.

> Psychologists define empathy as the ability to understand or feel what another person is experiencing, by taking the other person's perspective. Compassion takes empathy a step further, by awakening a desire to reduce suffering in the person whose perspective is being taken.

> With empathy, but without compassion, we can be disturbingly cruel. And maybe compassion represents a type of consciousness that really is unique to our species.

> Compassion requires not only the ability to understand what another person is going through and to suffer with that person, to essentially recreate their subjective experience in our own minds but also to feel an urge to minimize their suffering. Maybe compassion belongs in Sapolsky's second category, a thing for which we share tools with other species, who might show evidence of empathy, but which we've put to a novel use—to induce a feeling of wanting to help.

> Are there other examples of species who show behaviors in line with compassion? In one study, chimpanzees chose to give gifts to their peers even if their generous acts didn't seem to bring them any benefit themselves. This study shows that, at least when it doesn't cost them much, chimpanzees can consider the feelings and desires of their fellow monkeys.

COMPLEX BEHAVIORS

> Because we share so much DNA, and therefore behaviors, with other primates, it's not surprising that primitive elements of our own complex thoughts and feelings can be observed in these species.

- But we can see complex humanlike behaviors even in animals whose nervous systems are so different that they almost defy comparison. Take the octopus, for example. More than half of an octopus's neurons aren't in a centralized brain; they are in its tentacles. And each tentacle seems to have a mind of its own: If you sever it from the rest of the animal's body, it will not only crawl away, but if it encounters some food, it will take the food and try to put it where the mouth should be, were the arm still attached.

- Octopi in captivity have been shown to play with bottles like toys; play is a behavior that most people would agree is reserved for fairly intelligent animals. Aquarists will even tell you that these animals must have opportunities for play to stay healthy.

- The eyes of an octopus are very similar to ours, with transparent corneas, irises that regulate how much light comes into the eye, and a ring of muscles that focuses the lens. Yet with brains that are so structurally and functionally different, their experience of the world is surely vastly different from ours.

Octopi in captivity have been shown to play with bottles like toys; play is a behavior that is reserved for fairly intelligent animals.

- Still, the eyes of both species are wonderfully complex organs—so complex that many people have a hard time imagining how the eye could have evolved in tiny steps over many millions of years. Yet, given enough time and many incremental steps, nature can arrive at some pretty amazing end products.

- It's the same with consciousness. We often think of a conscious brain as qualitatively different from one that lacks consciousness. But if we look at it from an evolutionary perspective—if we think of incremental steps over millions of years—we shouldn't expect to see a stark dividing line between a conscious brain and an unconscious brain. There's not a sudden leap from one condition to the other. Rather, when we think in evolutionary terms, we start to appreciate how brains are a continuum. And human consciousness is the result of simpler processes.

SUGGESTED READING

Shettleworth, "Clever Animals and Killjoy Explanations in Comparative Psychology."

———, "Do Animals Have Insight?"

QUESTIONS TO CONSIDER

1. How much of your brain could be replaced with computerized implants before you stop being human?

2. Can we ever know whether other animals are conscious?

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CAN YOU MULTITASK EFFICIENTLY?

A popular misconception is that when we are multitasking, we are actually doing 2 things at once, doubling up on our efficiency. But the truth is that we're not: We're switching our attention between tasks, and every time we make a switch, we pay a price. And just like many of our cognitive biases, our memories, or the unconscious processes that shape our behavior, our intuition is not an accurate judge of how well we are switching between tasks.

MULTITASKING

> We are often impressed by how much busy people can accomplish. And for many people, the ability to squeeze more tasks into a day by doubling up on them is a source of pride rather than shame. But studies have shown that people who multitask more often, who consider themselves particularly good at it, are actually worse at it than the rest of us.

> What we don't know yet is whether this impairment is the chicken or the egg: Does multitasking lead to a greater susceptibility to distraction and a decrease in the ability to control your attention, or are people who are more distractible more likely to spend time trying to do 2 things at once?

> People who report multitasking often and who think they are particularly adept at it are also more likely to be impulsive and

to be labeled as sensation seekers: people who take more risks to get novel and intense experiences. So, it might be true that people who have shorter attention spans gravitate toward multitasking.

- But regardless of which way the arrow points, the increasing availability of multiple media at our fingertips is only going to make this problem worse. The more people succumb to the growing temptations to multitask, the more likely we're going to see adverse effects on their ability to focus on challenging tasks.

- For many people, the bigger issue is not just that we find it difficult to resist the temptation to entertain ourselves while we are at a stoplight or walking along the street. The problem is that the demands placed on us to be always available and to fit a busy work schedule and time for family and friends into a short day leaves us with few opportunities to spend a significant amount of time doing only one focused thing.

> Multitasking, in the real world, isn't just about listening to music while we work on a project; instead, it's what society demands of us, now that we are so easily contacted and connected. So, we can't just avoid it altogether. But too often we let all these demands distract us from important activities that require a maximum of focus, leaving a trail of unfinished projects and unfulfilled dreams in our wake.

OUR BRAINS AND MULTITASKING

> Our brains are creatures of habits: If you do the same thing over and over, the networks of neurons that are involved in that task get strengthened and fire more efficiently. That means that the next time you do that thing, your brain's activity will be slightly more fine-tuned. But it's also more difficult to then take a different path.

> When you multitask, your brain doesn't necessarily know which task is the important one. And the brain is metaphorically lazy; it will gravitate toward the easy, more sculpted track. So, if you're doing 2 tasks, one of which is more ingrained, you'll find your mind drifting back to that one rather than paving a new track.

> If you're multitasking while you're also attempting to learn something new, you're creating a specific context, which your brain is making note of. It doesn't know that the background activity is not an important part of the foreground one.

> For example, if you're listening to music while studying, your brain is making associations between the music and what you're working on. When it comes time for you to retrieve the information you've been trying to learn, however, without the music, it might be more difficult for you to get your brain in the right gear. But play the music again, and you might find that it triggers some remembering—which is probably not what you intended in the first place.

- But even perhaps more nefarious is the illusion that you're learning when in fact you're not. According to the Mozart effect, engaging in pleasurable activities keeps you feeling good in the moment. But you likely aren't doing the hard work of learning by engaging deeply with the content.

- Some tasks aren't always enjoyable, and making them enjoyable via distraction doesn't mean you are accomplishing what you set out to do, even if, by the end of the TV show episode, you've made your way to the end of the textbook chapter.

- However, a study showed that listening to music heightened arousal in students and led to better performance on a subset of cognitive tasks. Eating a chocolate bar or drinking coffee before or while studying can also help. But arousal only helps if the arousing task doesn't interfere with learning—doesn't involve the same cognitive processes as what's being used to keep you entertained.

- Multitasking is rewarding because we generally are entertained by at least one of the tasks, and we minimize the negative aspects of the other. So, the overall experience is positive. Then, when faced with just the negative task, we remember the good times of multitasking and have a more difficult time staying focused.

- Why can't we just do those 2 things at once? If we're using our conscious effort to accomplish both things, we really can't do more than one at a time. Instead of doing 2 things that require conscious awareness at the same time, we do one and then switch to the other.

SWITCHING BETWEEN TASKS

- There are an almost infinite number of different ways that we can multitask, and each of the subtasks will have a different neural signature, so putting them together will also show different patterns of brain activation.

- Note that we've moved away from the view that a task activates one brain region. Instead, we talk about networks of brain regions, because this nomenclature more accurately captures what we've observed during neuroimaging studies: Many different regions interact to accomplish a particular task. What comprises a network can shift from task to task, as one task might involve language regions and the visual cortex while another might require visual processing and motor activity.

- And the more demanding a task, in general, the greater the activation we see in that network. Just as with attention allocation—a more difficult task requires more attention, leaving less attention available for other tasks—with brain activation, the greater activation there is during the performance of one task, the less can be redirected to another.

- The more overlap there is between the 2 activities, in terms of their neural signature, the more interference we see from one task to the other, and the poorer the performance on one or both tasks.

- Even putting aside the decreased resources that we can spend on each task, every time we switch our attention from one task to another, we pay a price. Sometimes the price is small and we can corral our attention back fairly easily. Often, in fact, we're pretty quick at making the switch. But sometimes the cost is bigger than we think: Instead of a switch cost, we pay a price for mixing the 2 cognitive tasks, called a mixing cost.

- The mixing cost is a measure of the extent to which the previous task intrudes into the current one: If you are switching between checking email and preparing a presentation, the mixing cost can be pretty expensive, as you keep thinking about your emails even though you should be thinking about your talk. We fall into a trap of wasting too much time, and then having even less dedicated time to do the thing that we were supposed to be doing.

- From studies in which psychologists asked participants to switch between tasks and measured the amount of interference that one task had on the other, we can draw 3 broad conclusions:

    - The more similar 2 tasks are—the more they overlap in terms of what cognitive processes they engage—the more they disrupt each other.

    - Dividing attention between tasks is less effective when one or both of the tasks are difficult.

    - Doing 2 things at once is nearly impossible when both tasks require your conscious attention.

- We can think about brain activation to give us some clues as to why this is: Learning a task often recruits a larger network, and training makes that network more efficient, requiring less

activation to accomplish the task. So, if you're learning, you need to devote more resources to the task—leaving fewer available for other things.

> These 3 principles can explain why we seem to be able to do more than one thing at a time with practice: When a skill is practiced enough, it no longer requires conscious thought and it's easy, making more cognitive resources available to you for other types of thinking.

> How you mix your tasks is also a factor. It's easier to switch from a task that you're not very good at to one that you do well than the other way around.

> That's why so many gurus advise us to tackle the difficult tasks first. It's easier to go from the difficult, less familiar task to the more familiar ones. But after an hour of checking email, which we're all good at by now, it's much more difficult to then sit down and compose a brilliant essay.

MYTH

When you're multitasking, you're doing more than one thing at once.

TRUTH

When you think you're multitasking, you're actually switching quickly between tasks, and each switch comes at a cost.

> Tasks like checking email, which are really made up of many short tasks, exhaust our minds more than we think they do. Making decisions, which emailing really boils down to, is tiring. After making a bunch of trivial decisions, such as whether to respond right away or file the email until later, we have fewer cognitive resources available to weigh the pros and cons of more important decisions. Psychologists call this decision fatigue.

BENEFITS OF MULTITASKING

> For a long time, psychologists cautioned parents against teaching young children more than one language, worrying that the

children would get confused. And there is evidence that bilingual children take longer to develop as rich a vocabulary as their monolingual peers.

> But an unexpected benefit of bilingualism seems to be an improvement in the ability to multitask. Because children who grow up speaking 2 languages have to learn to switch between them early on, their brains wire differently, and they seem to show better executive functioning, on average, than monolingual children.

> It's possible that having to hold multiple words for the same concept in mind simultaneously trains working memory functions. Indeed, we see working memory benefits in bilinguals; they perform better on tests of verbal and visuospatial working memory. Bilingual children also have to learn to inhibit the intrusions of words from the wrong language, so they develop inhibition skills that are one of the keys to success in task switching.

> Such benefits are especially pronounced in children coming from lower socioeconomic households. And many immigrant families start off poor in a new country. That's why the myth that children born into these families should only be taught the language of their new country needs to be rethought.

> There's a wealth of studies of skill learning that show that massing practice—doing the same thing many times in a block—is not as effective as spacing your practice sessions across time. Even in a single practice session, it's less efficient to play the same passage over and over again than to interleave practice trials with each other—practicing the passage once or twice, then practicing a different passage or a different skill, then coming back to the original one.

> Can training improve multitasking ability? The answer is yes, although just multitasking itself might not do it. You need to have a strategy of how to get better at it. Usually, the strategy is to practice each task on its own before putting them together.

- Brain imaging studies of this sort of multitask training show that the networks involved become more efficient, just as we would expect, rather than seeing a pattern in which new regions are recruited. We also see an increase in the speed of processing in the prefrontal cortex, underlining this increase in efficiency.

- But multitasking the way most people do it—alleviating the boring nature of one task with a more stimulating bit of entertainment—reduces our performance and our learning of the difficult task.

SUGGESTED READING

Bowman, Levine, Waite, and Gendron, "Can Students Really Multitask?"

Burgess, Veitch, de Lacy Costello, and Shallice, "The Cognitive and Neuroanatomical Correlates of Multitasking."

Pashler, "Dual-Task Interference in Simple Tasks."

QUESTIONS TO CONSIDER

1. When you switch from one task to another, do you get intrusive thoughts from the first task? What kinds of tasks are the worst culprits?

2. Sometimes, though, doing another task concurrently with one that is a bit boring can give you the energy to complete it. Why? What types of tasks are most compatible?

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ARE DREAMS MEANINGFUL?

We dream every night. And we love to talk about and analyze our dreams. Yet they still remain shrouded in mystery. Many people have argued that dreams have universal meanings and that, if understood, they can give us useful information about ourselves, our past, and even perhaps our future. But there is a more scientific explanation for why we dream and what our dreams might actually be made of.

WHAT IS DREAMING?

> Dreaming is difficult to study empirically. That's because it's difficult to know, with the tools we currently have, what people are dreaming about unless they can tell you about it in the moment. And people can't tell you what they are dreaming about while they are dreaming because they're unconscious.

> Instead, we need to wake them up and ask them what they remember having just dreamt. There's a major problem with this method: Your conscious mind probably thinks very differently from your dreaming mind. At least that's what the brain activation comparisons suggest, showing that the activity in your brain is very different while you're awake compared with while you're asleep.

> How your conscious mind interprets the activity in your unconscious mind might be very different from what you actually experience in the dream state. In the simplest case, while dreaming, you're

not being bombarded with sensory information that is coming from outside of your brain. Instead, your brain is generating the sensory experience itself—it's hallucinating.

> When we consider what a dream is, we need to think about the mental state that makes dreaming possible. But because we can't get direct information from that state, we can only really study the waking mental state that follows. It's not a very transparent lens into dreaming, but right now, it's all we have.

> It's entirely possible, if not highly likely, that your interpreter, the part of your brain that actively works to make sense of what's going on in your mind, is very active when you're remembering elements of your dream. And the interpreter is not very trustworthy, so we have to admit that the reports of our dreams might be polluted by other cognitive processes, such as remembering and interpreting.

> For the most part, we consider dreaming outside of our control. Only in a special type of dreaming, called lucid dreaming, do we actually have control over what's happening. So, dreaming is a conscious report of a mental experience over which we have no control.

> We need to set some boundaries to study the phenomenon of dreaming. We can distinguish, for example, dreaming that occurs just as we're falling asleep from dreaming that occurs while we're deeply asleep and dreaming that occurs just as we're waking up.

> If we stick to our definition of dreaming as a mental activity in an unconscious state, then we need to include thinking during sleep, and that happens in all stages of sleep. When we think of dreaming, most people don't have in mind any thought that happens while asleep. Rather, we tend to think of dreams as the often bizarre storylines that unfold during the stage of sleep called rapid eye movement (REM) sleep.

> The name for this stage of sleep comes from the fact that, during it, our eyes are darting left and right underneath our eyelids, as though we are seeing events unfold in our mind's eye. But is that what the eyes are really doing? Is that darting a function of looking or something else entirely?

THEORIES OF DREAMING

> The person who is perhaps most famously associated with dreaming is Sigmund Freud, who proposed that dreams are evidence of a disguised censorship in our minds. By interpreting the dreams of his patients, he noticed that the language of dreams is not direct, but he felt that psychoanalysts can decipher a person's true fears, wishes, and desires if they can uncover the information that is being censored during the dreaming process and unshackle themselves from past disappointments.

> The problem with Freud's theory is that it's not testable or falsifiable. Because science works by eliminating hypotheses that we know are wrong, we can't call his theory scientific. Another problem is that different analysts have been shown to interpret the same dreams in different ways. That means that analysis is to some extent subjective, which means that it can't be fully objective—which science must be.

> A scientific theory of what our dreams mean was proposed in 1977 and is called the activation-synthesis hypothesis, which states that dreams are just the result of your interpreter trying to create a story out of random neural signaling.

> When we enter REM sleep, large waves of activity wash over the brain. The activation-synthesis model proposes that these waves activate different brain regions randomly—that's the activation part. Then, the cortex tries to synthesize this activity—to make sense of it—by concocting a story or tying images together, and so forth.

- These ideas called Freud's work into question, and proponents of the model insist that dream interpretation is mumbo jumbo—because there is no meaning in the dreams. Dreaming is just your cortex trying to make sense of random electrical activity across the brain. This model rocked the foundation on which Freudian analysis was built.

- The activation-synthesis hypothesis has some real limitations. For example, it predicts the way that we dream—the visual images, the bizarre nature, the distortions—but it doesn't speak to what we dream. The model doesn't explain the content of our dreams in any satisfying way.

- There are now a series of theories that do attempt to address content. One idea is that dreams play a role in memory consolidation, firming up memories of things that are important to us and erasing irrelevant information. Certainly, sleep as a whole is involved in this process, but the question remains concerning the extent to which dreams are an integral part or simply an innocent bystander.

- In the dream-to-erase theory, for example, scientists suggest that if we remembered everything that we experience each day, we'd have serious problems with interference, overlapping representations, and ultimately a system failure akin to what happens when your computer runs out of memory.

- We see a version of this problem in people who have highly superior autobiographical memory—rare individuals who can remember every day of their lives. These people have obsessive-compulsive tendencies. Their memories become intrusive, and remembering takes up much of their conscious time, even when they don't want it to.

- Proponents of the dream-to-erase theory suggest that dreaming is an artifact of how unnecessary information is removed from the brain, leaving it more efficient and running smoothly, much like

a cleaned-up computer. While you dream, you replay things that happened in the past, strengthening the important associations and getting rid of the irrelevant stuff.

> In this view, dreams don't mean anything; they are just part of the mechanism by which the brain declutters itself.

> This idea, that dreams function as a cleanup crew for unimportant sensory information, dates back to the 19th century and was even included in Freud's famous tome on dream interpretation. It's compelling because it seems to solve the problem of how our brains seem to be capable of learning a limitless amount of new information every day, even as most of that information is forgotten after 24 hours, or our first sleep period.

> The major problem with the dream-to-erase theory is that we haven't found evidence yet of active erasing during REM—that synapses that were previously strengthened, for example, are being weakened in this state. But the idea that sleep performs cleanup, with a higher cerebral spinal fluid volume and a buildup of toxic by-products of metabolism in people who aren't sleeping enough, remains influential.

> There are different levels of attention and consciousness. We can focus intently on one activity or let our minds wander. When we sleep, our focus is looser still, as most people relinquish control of their thoughts to the dream weaver.

> Most current scientific theories of dreaming agree with this characterization so far (minus the weaver). But whether the content of dreams is just random, a by-product of the sleeping brain (as in the dream-to-erase theory), or more meaningful (as Freud suggested) is where the theories diverge.

> In the contemporary theory of dreaming, developed by Tufts University professor Ernest Hartmann and others, the content of a dream is thought to be generally driven by emotional networks

in the brain. The evidence that theorists point to is varied, but it begins with the finding that after an emotional event, particularly a traumatic one, the intensity of dreams is greater, as is the frequency of intense dreams.

- The fact that what we do during the day often makes an appearance in our dreams is not a new observation. This is one aspect of dreaming that Freud got exactly right.

- But we don't usually dream about parts of our day that were emotionally neutral, such as brushing our teeth or writing emails, even though we spend a lot of our time doing these run-of-the mill things. In the contemporary theory of dreaming, the emotional content is selected for and given center stage.

- Ernest Hartmann suggested that dreams are a way by which the brain can integrate traumatic or emotional material with more neutral memories, weaving the information in and thereby decreasing the emotional response to the content of the trauma.

- Several studies have shown that depriving an individual of sleep disrupts the consolidation of emotional memories in particular. They also show that REM sleep—the stage of sleep in which people are most likely to report having dreamt—plays a key role in consolidating these memories. Once consolidated, these memories are more easily recalled, especially when they result from negative emotional experiences.

- It's difficult to study the content of dreams, but we can objectively measure sleep stages and therefore uncover the effects of

MYTH

Dreams are how your subconscious communicates its desires.

TRUTH

Dreams likely simply reflect the interpreter's attempt to make sense of random neural firings.

different stages on different aspects of brain function, such as emotional memories.

> REM sleep is a good candidate for emotional therapeutic work, as sleep expert Matthew Walker at the University of California, Berkeley, suggests. It's the time of night when the brain cells that pump serotonin, norepinephrine, and noradrenaline—neurotransmitters that are involved in mood regulation—are most strongly inhibited. That means that during REM sleep, when we are most likely to dream, our brain contains only low levels of the chemicals that signal anxiety and other emotional states.

> At the same time, Walker notes that there is increased activity in the parts of the brain that encode, consolidate, and retrieve emotional memories: the hippocampus and amygdala, along with other regions that are part of the limbic system, which is the seat of our emotional life, especially when it comes to memories. There is also increased activity in cells that provide the brain with acetylcholine, a neurotransmitter with a large number of functions, including arousal and attention.

> Walker has put forth a detailed account of the relationship between dreaming and our brain's processing of emotions, in line with the contemporary theory of dreaming. The punchline is that during REM sleep, our brains work through past emotional experiences, stripping away the anxiety and stress from the semantic content—the useful information that we want to take away from the experience.

> Walker and colleagues point to the fact that limbic regions that contain emotional memories are active during REM sleep and mood-related neurotransmitters such as serotonin and norepinephrine are at their lowest levels. This combination suggests that we relive our memories, but we don't feel the emotions they contain when we dream.

- At the same time, our brains are low in adrenaline and full of acetylcholine, a neurotransmitter that modulates our attentional system. That means that the memory can be reactivated and strengthened, and disassociated from the emotion.

- It's a beautiful model. And it might explain why individuals who suffer from post-traumatic stress disorder have disturbances in their emotional memories.

SUGGESTED READING

Edwards, Ruby, Malinowski, Bennett, and Blagrove, "Dreaming and Insight."
Selterman, Apetroaia, Riela, and Aron, "Dreaming of You."

QUESTION TO CONSIDER

1. How often do you remember your dreams? Do they tend to have the same themes? What does that tell you about the types of worries or thoughts that occupy your waking state?

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CAN BRAIN SCANS READ YOUR MIND?

It's only been in the last few decades that we have been able to see neural activity inside a living, healthy brain. Within this period, the techniques have improved, but the amount of misinformation and misuse of neuroimaging data has exploded. There have been many media outlets that have reported on studies apparently showing that brain scans can tell whether a person is lying or telling the truth, for example. Despite the public's perception that brain scans can tell if a person is lying, we're simply not close to achieving that.

NEUROIMAGING TOOLS

> There are several different ways in which we can measure brain activity in a healthy person. We can record electrical potentials—that is, averaged neural activity across many neurons—by placing electrodes on the scalp. This is called an electroencephalogram (EEG), and it gives us a sense of what ensembles of neurons are doing at a very specific point in time.

> We can also see where cells have just been active by tracking the amount of oxygen in the blood flowing to that region. Because active cells require oxygen, we can use magnetism to detect changes in the oxygenation of blood in different parts of the brain. This is how MRI tools have been repurposed to see activity—or functional MRI (fMRI), with which we see where brain cells are more active compared with some baseline activity.

- Positron-emission tomography (PET) scans are also still used, though less frequently, because they provide much of the same information that we can garner from fMRI but involve the injection of a radioactive substance that is then tracked as it's taken up by active cells. It's largely reserved to diagnose neurodegenerative diseases or cancer, rather than to investigate cognition.

- There are other ways that we can track electrical activity or blood flow, but the principles of how we interpret those data are essentially the same: We want to see what parts of the brain, or networks, more specifically, are active when a person is doing something that we're trying to understand, such as improvising music, solving a problem, remembering the past, or lying.

- This activity tells us that a large number (millions) of neurons are firing action potentials—sending signals to each other—around the same time. These signals can be complicated. An increase in firing does not always mean the same thing. For some cells, their

baseline firing rate is pretty high and it's a decrease in firing that is meaningful.

- Some regions are likely making computations that don't involve millions of cells firing in unison. In some regions, the signals might be more specific and the relevant information might be coded sparsely—that is, only a few cells are triggered by an event.

- But note that the pictures of activated brains that we often see in the media are not what they seem: They are not literal photographs of neurons firing. They are statistical maps, often indicating where in the brain the tools found more active cells.

- The shapes of these maps depend on where the experimenter sets the statistical threshold. If the scientists lower the threshold in their analysis, there will be more active areas. If they raise it, there will be fewer.

- There are also neuroimaging studies that focus on the volumes of different brain structures, rather than their activity—the relative sizes of different regions. These maps can look very similar to activity maps to the uneducated eye, but they aren't saying the same thing. The size of a structure isn't the same thing as how active it is.

- From the use of neuroimaging tools, we have learned that much of the brain is active all the time, no matter what we're doing, and that these activations often follow patterns, with some regions fluctuating in activity in sync and other regions acting more independently.

- These findings have reshaped how we think about the brain, moving away from thinking about it as a modular machine, with different regions having different functions, and toward a more networked view, talking about brain circuits that work together.

- As a person develops a skill, the functional maps that represent different stages of training can be distinguished from each other: In general, first more regions are recruited to help the person perform the task. With practice, these regions begin to act more efficiently, with maps showing fewer areas involved but a greater amplitude of the signal.

- Neuroimaging techniques have had a profound influence on our understanding of the brain, from its networking to its plasticity and many more findings in between. But they are also too easy to misinterpret and overstate.

- Before we decide to use some imaging tool to track brain activity or structure, we need to understand what the information gleaned from that tool would actually tell us. Sometimes, the additional information that neuroimaging gives us isn't as useful as the additional information that we can gain by getting a deeper understanding of the behavior we want to study.

- Experience is subjective. If you activate a part of your brain while you're doing something, we can't be sure that you're activating it for the same reasons that another person might be. As the technology currently stands, the differences between 2 people might be invisible to neuroimaging.

- Most of the brain's regions have many functions, and just because a region is active, we can't be sure exactly which function it's performing unless we know more about the behavior in question. That's why the best neuroimaging studies involve carefully crafted tasks that neuroscientists have studied long enough to know how our minds are engaged by them.

- Only when we understand the behavior well can the brain activity it generates be informative. Brain imaging data are only one more tool that scientists can use to probe the mind; they should be considered in addition to work on patients with brain damage and behavioral experiments, not as a trump card.

THE AMYGDALA

> There are several regions in the brain that are most often singled out by the media and that have become the subjects of the most common misunderstandings. Three of these are the amygdala, which is involved in modulating emotions; the reward circuitry that responds to dopamine surges; and the prefrontal cortex, which is evolutionarily our most recent addition.

> The amygdala is an almond-shaped structure in the medial temporal lobe, deep in the brain roughly behind your ears. Like many brain regions, the amygdala does a lot of things. From patients with amygdala damage and from animal studies in which the amygdala is lesioned, we know that without it, we don't see the usual memory enhancement that accompanies emotional events.

> Despite common belief, we don't usually repress negative memories. Negative emotions such as fear or anxiety reinforce the vividness of an event: We tend to remember more details of the environment and other aspects of the experience. But people and animals with damage to the amygdala don't preferentially remember these experiences.

> The media often interprets amygdala activation as a sign that we're fearful of something or that our behavior is somehow driven by fear. But if the emotions we feel during the event are positive, the amygdala notices those, too, and plays a role in making sure that you learn what it was that led to a positive result.

> But the story is much more complicated than that. Damage to the amygdala can make people experience less fear, but they will still react to fearful faces. Animals with lesions to the region show a decrease in sexual, aggressive, and maternal behaviors.

> People with a larger amygdala on the left side are more likely to be taking medication or in psychotherapy for the treatment of depression. They are more likely to have obsessive-compulsive

disorder, borderline personality disorder, and post-traumatic stress disorder. Social phobias are correlated with more activity in the amygdala.

> But children with anxiety disorders often have a smaller than normal amygdala in the left hemisphere. The size of your amygdala also correlates positively with the size of your social network. The bigger your network, the bigger your amygdala.

MYTH

Neuroscientists can read your mind by scanning your brain.

TRUTH

Your brain is a Swiss army knife or a multipurpose tool: Many parts of your brain have many different functions, and when a part of your brain is active in a brain scan, we can't always tell which function it's accomplishing.

> The amygdala has a number of different subregions, each of which might make a different contribution to the emotional modulation of our experiences. So, the amygdala is involved in much more than just fear and aggression.

> When a study reports that the amygdala is differentially active during a particular task or in a particular group of people, on the surface, we don't know what that means. We have to learn more about the behavior in question or the group we're studying before we can interpret such a result.

> Just because the amygdala is implicated in one function in one study doesn't mean that it's playing the same role in another. Your amygdalae might light up if you watch a scary movie, but that doesn't mean that if they light up when you watch a romantic comedy, you're somehow showing a fear response to intimacy. The reverse inference can't be made. This type of reverse-inference making is rampant in the media, but it is almost never warranted.

DOPAMINE

> Reverse inference seems especially tempting when the reward circuitry of the brain is involved. The neurotransmitter dopamine has many different functions in the brain. It's involved in our sense of pleasure and our sense of pain. It is called up when there is something in the environment that might predict reward or punishment.

> But it also plays a role in helping us hold information for a few moments, in working memory. It also plays a role when we get nauseated. Too much dopamine in the wrong places can cause hallucinations, not just euphoria. And too little messes up your ability to control your muscles, leading to Parkinsonian symptoms.

> Each of the brain regions involved in processing rewarding information also plays multiple roles, so we can't infer that someone is feeling pleasure just because his or her reward pathways light up. Again, the reverse inference doesn't necessarily hold.

THE PREFRONTAL CORTEX

> This is perhaps even more true for a region such as the prefrontal cortex, whose functions vary from keeping your impulses in check to remembering what you need to pick up at the grocery store to making complex long-term plans for your future. Of all of our brain regions, the prefrontal cortex is perhaps the most complex in terms of neatly assigning function.

> It's also highly interconnected with other brain regions. So, it seems to have a hand in virtually any kind of thinking that we do.

> How can we possibly use reverse inference to give us any kind of deep understanding with respect to the prefrontal cortex? How can we interpret activation in this region if we don't understand what type of thinking the person in the scanner is doing?

- In studies that fail to find activation in expected regions, can we conclude that those regions aren't involved in the function that we're testing? The answer is no, because there are many technical reasons for why we wouldn't observe greater activation in a particular region.

SUGGESTED READING

Henson, "What Can Functional Neuroimaging Tell the Experimental Psychologist?"

Poldrack, "Can Cognitive Processes Be Inferred from Neuroimaging Data?"

QUESTIONS TO CONSIDER

1. Why can't we use reverse inference to interpret neuroimaging data? For example, why can't we say that if the caudate nucleus was activated while you were watching a political video that you must have enjoyed the video, because the caudate is part of the brain's reward system?

2. Would you ever want to upload your brain into the "cloud"?

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CAN ADULT BRAINS CHANGE FOR THE BETTER?

Unlike most of the other cells in our bodies, our neurons stick around, most of them our partners for life. That's why neural development in childhood is so critical. At the other end of the lifespan, these cells are subject to some of the same effects of aging that deteriorate other parts of our bodies. For decades after the first evidence that demonstrated the birth of new brain cells even in adults was published, many neuroscientists refused to shed the dogma that once we reach adulthood, we only lose neurons—we don't grow new ones. But this is a myth.

NEUROGENESIS

> Neuroplasticity refers to the long-lasting changes that a brain can undergo throughout the course of our lives. Like plastic, the brain can be shaped into a billion different forms, giving each person who ever lived a unique mind. There are some brain functions that seem to be more amenable to change than others, and there are times in our lives when our brains are more plastic than at other times.

> A protein called brain-derived neurotrophic factor (BDNF) plays an important role early in our lives as it encourages the growth of new neurons and the formation of new synapses so that cells can communicate with each other. It's prevalent during critical periods, in which neurons are finding their places in the brain—a time of extensive neuroplasticity.

> These critical periods are why children who are not exposed to certain types of stimuli—if they are deaf, for example, or aren't spoken to—must then endure a lifetime of disability. If a child doesn't get the right type of stimulation, his or her cells won't organize themselves in such a way that they can process that information later in life.

> But the work of BDNF isn't finished once a child reaches adulthood. Even in adulthood, we now know that we do grow new neurons in select parts of our brain: regions involved in long-term memory. So, the idea that once you reach your 20s, you're stuck with the brain cells that you have is a myth.

> But note that neurogenesis doesn't happen all over the brain. That would be a disaster. Instead, we have found adult neurogenesis in only 2 parts of the human brain, both of which are involved in creating memories: in one region of the dentate gyrus, a very specific part of the medial temporal lobe involved in the rapid formation of new long-term memories; and in the striatum, which plays a role in planning actions, reinforcement, motivation, and decision making.

> In the striatum, the cells born in adulthood are interneurons exclusively; that is, they don't connect to cells outside of their immediate vicinity. In the medial temporal lobe, the new neurons turn into granule cells, which are small, tightly packed cells whose reach is also limited locally.

> We think, therefore, that adult neurogenesis enables us to encode new memories, giving us the opportunity to learn throughout our lives, but it doesn't interfere with connections that we've made from previous experiences.

> Some of the first evidence that we grow new neurons came from bird brains. In the 1980s, scientists discovered that canaries grow new neurons in the hippocampus, the avian analogue of our own

memory powerhouse, when they are learning new songs. And the more complex the repertoire, the larger their hippocampus.

> After this discovery in songbirds, other nonflying animals were shown to possess the ability to grow new brain cells. Neurogenesis in adulthood was reconfirmed in rodents, our mammalian cousins with whom we are relatively close genetically.

> From rodents, we've learned that the speed at which new neurons are born can vary; rich environments that provide a lot of stimulation can increase neurogenesis. Memory tasks and socializing and even simple play can, too.

> In one study, rats that got a lot of exercise—for example, by running on a wheel—doubled their neurogenesis rate compared to sedentary ones, who weren't provided with a running wheel.

> It's not enough to just grow new neurons—they also have to survive. Animals who were then given the chance to learn a new skill were left with a greater proportion of surviving new cells compared with a control group, who experienced neurogenesis but then weren't given the opportunity to put those cells to action by learning a new skill. The new neurons need to be integrated into adult brains, and that doesn't happen if the animals aren't challenged.

MYTH

After your brain develops fully in your early adulthood, it just starts a long, slow decline.

TRUTH

The brain continues to be changeable throughout your lifespan.

> Despite the large similarity between our brains and those of rats, there were still prominent neuroscientists who refused to believe that adult neurogenesis was also a human thing. Then, at the turn of the 21st century, a collaboration between scientists in Sweden

and San Diego finally demonstrated the phenomenon in our own species.

> The authors had learned that the same dye used to track neurogenesis in rodents had been injected in certain cancer patients over the previous decades. They then got access to their brain tissue postmortem and found the same evidence of the birth of new cells throughout the lifespan in these people.

> But more questions remained. Now the field wondered what role neurogenesis plays in the human mind, what circumstances affect its rate, and whether we can treat devastating brain diseases with neuronal stem cells.

> Since 2013, neuroscientists have learned that not only is neurogenesis a common feature of the adult brain, but that there are important differences between neurogenesis in rodents and in humans.

> In the mammalian brains that have been studied, the growth of new brain cells is restricted. So far, we've found that in rodents, these neurons end up in either the olfactory bulb, which is responsible for smell, or the dentate gyrus, a subregion of the hippocampus that is involved in learning and memory.

> The neurons that are born are fairly small and make connections only with neighboring neurons—they stay local. That makes sense, because integrating new cells into complicated circuits might be a recipe for disaster.

> Both rodents and humans grow new neurons in the hippocampus. The other place where new neuron growth begins is called the subventricular zone in the lateral ventricle. In rodents, these neurons then migrate to the olfactory bulb, likely because the sense of smell is of critical importance to a rat.

> But in humans, those cells migrate to a part of the brain called the striatum, responsible for coordinating movement and critical for long-term learning of motor and other skills—called procedural memory.

> One more interesting difference between rat and human neurogenesis goes exactly against the logic that some neuroscientists clung to in justifying their rejection of the initial findings: the idea that humans can't possibly grow new neurons because we can remember things from our very remote past.

> The idea was that if memories are stored in neural networks, those neurons need to remain intact for us to be able to retrieve old memories. If there was a turnover of neurons the way there is of skin cells, we would forget our past.

> In rats, the proportion of new neurons in the dentate gyrus doesn't seem to ever exceed about 10% to 20%. But in humans, by about age 50, the majority of neurons in the dentate gyrus have turned over.

> How, then, is it possible that we can still remember old memories? There is growing evidence that the dentate gyrus may play a bigger role in encoding new memories than in retrieving them.

> In fact, rats with dentate gyrus lesions have trouble learning new things but not remembering old ones. Lesion a different part of the hippocampus, one in which there isn't adult neurogenesis, and you get the opposite pattern: The animals can learn new things but can't remember old ones.

> That would make sense. We'd need the new cells in the dentate gyrus to form new memories, but then those memories would be ultimately stored elsewhere, and we wouldn't need that region to retrieve them. Instead, baby neurons there would now be available to lay down a new set of memories, leaving us with the ability to learn new things until the day we die.

INFLUENCING NEUROGENESIS

> There is a connection between BDNF and neurogenesis even in adulthood. You can influence the amount of BDNF floating around in your brain and the growth of new neurons with a fairly simple and cheap treatment: exercise.

> Several studies have shown that regular exercise can lead to a threefold increase in BDNF levels. Even a single session can make a difference. Exercise is effective at ramping up neurogenesis and keeping those cells integrated in the brain.

> While exercise can increase adult neurogenesis, stress can impair it. In animal models of depression, neurogenesis decreases under experimental conditions where the animals are placed under stress. In these same experiments, administering antidepressant medications to the stressed animals has been shown to restore neurogenesis to healthy rates.

> There are other examples of people who successfully increase the volume of specific parts of their brains by training or learning a new set of skills—not necessarily by growing new cells, but by increasing the connections between them.

> For example, juggling every day for 3 months has been shown to increase the volume of certain parts of the brain, including the hippocampus—in 20-year-olds and in 60-year-olds. While the 60-year-olds weren't juggling as well as their younger counterparts with the same amount of training, they still showed increases in brain volume. But once the participants in these experiments stopped juggling, the regions returned to their previous sizes.

> In addition, it seems that musical training can drive brain volume increases in the parts of the brain that are engaged by the activity.

> As we get older, we tend to spend less time learning new things or engaging our brains in effortful ways. And given that this effort is what seems to benefit our cognitive function and our brain structure in measurable ways, our lifestyle choices play a significant role in whether or not we experience cognitive decline with aging. And that experience, in turn, can affect our very attitudes toward longevity.

> Science writer David Ewing Duncan conducted an online survey on the question of how long people want to live and found that out of more than 30,000 responses, more than half of respondents agreed that somewhere around 80 is a good enough lifespan.

> If we managed to stave off physical and mental decline and save enough money to economically sustain an extended retirement,

most people would probably push out their desired lifespan, perhaps past 150.

> When it comes to cognition, there are hints that interventions designed to keep the body healthy, such as exercise, have powerful effects in terms of staving off age-related mental decline. But what about the people who seem to be able to stay mentally sharp well into old age? Is there something we can learn from these types of people?

> There are several labs now studying not only healthy aging but super-healthy aging—people who thrive in old age and who score as well as people who are 20 to 30 years younger.

> In one study involving around 30 of these people, scientists found that their anterior cingulate cortex, a region of the brain responsible for cognitive control, resolving conflict, keeping up motivation, and perseverance, among other executive functions, was not only larger than that of their 80-year-old peers but also larger than the average size in middle-aged people.

> We still have a long way to go before we can make any solid conclusions about what factors combine to support such successful aging. Certainly, genes are a factor: For most people, lifestyle choices have a greater influence on our risk of death before age 80, and genetics seem to account for more of the individual variability in overall health once we reach our ninth decade of life.

> Super-healthy agers are pretty varied, but what they may have in common, at least anecdotally, is that they have remained active members of their community, socializing regularly.

> There's one more brain finding in this group that's been reported: They have 3 to 5 times more von Economo neurons in their anterior cingulate cortex than their peers. These large cells are thought to play a role in facilitating social interaction.

SUGGESTED READING

Barnea and Nottebohm, "Seasonal Recruitment of Hippocampal Neurons."
Deng, Aimone, and Gage, "New Neurons and New Memories."

QUESTIONS TO CONSIDER

1. What are some changes that you've noticed in terms of how you think over the years?

2. What would you most like to change about your brain? How do you think you might achieve those changes, given what we know about plasticity and its potential and limitations?

22

DO SPECIAL NEURONS ENABLE SOCIAL LIFE?

Some prominent neuroscientists credit the birth of a class of cells called mirror neurons with the cradle of civilization, explaining everything from empathy to tool use. Hidden in this hyperbole is an interesting kernel of truth that is worth exploring. Another set of cells, called Von Economo neurons, are perhaps even more fascinating than mirror neurons, though just as prone to being overhyped. Both cells play a role in human social behavior, and civilization is built on the foundational fact that humans are social animals.

SOCIAL NEUROSCIENCE

> Social interaction is critically important to us, and the selection pressure that shaped our brains during our evolutionary history was likely driven largely by our ability to get along. We don't know for sure why natural selection favored specific cognitive traits or why our brains evolved to look as they do today. But there are some ideas that are more compelling than others.

> Social neuroscience is a relatively young field, and we still have a lot of mysteries to solve. Yet some of the most interesting questions about our species are contained within this discipline.

> Around the time that the fossil record shows an exponential increase in our skull size, suggesting a corresponding increase in brain size, our ancestors began living in larger social groups.

- Some scientists have suggested that our larger brain size was selected for as we began to use tools. But tool use coincides with the formation of communities, and the social brain hypothesis, proposed by British anthropologist Robin Dunbar, is perhaps more convincing than one in which tools are the driving force shaping our brains.

- Dunbar set out to understand grooming behavior in primates, and in the course of his research, he noticed a trend: The bigger the social group in which the primate lives, the bigger its average neocortex.

- He then built a model that he could use to predict the social size of a primate group, given its neocortex size. Then, he stumbled on an interesting way to apply this model: to figure out how large a social network humans can reliably sustain.

- Dunbar recognized that among primates, our social group size is fairly big. Our nearest cousins, the chimpanzees, live in social

groups that contain about 50 individuals. And our brains are much bigger.

> Given our neocortex size, Dunbar's model suggested that we could maintain somewhere between 100 and 200 casual friends, those whom you'd invite to a big party. The average is 150, and this number is called Dunbar's number.

> Dunbar suggests that much of our minds have been shaped by natural selection to enable us to navigate social relationships—build communities that are cooperative and beneficial to individuals—but that there is an upper limit to a good group size.

> Dunbar examined human social groups and found some fascinating regularities: We tend to spontaneously form groups of certain sizes. Our best friends and family members, or our most important support system, is made up of 3 to 5 individuals. Then there's a circle of 9 to 15 people who are your close friends. Then there's the 30 to 45 people whom you'd invite over for dinner or with whom you socialize fairly regularly.

> Dunbar has found support for his predictions in historical records, army regiments, and social media apps, such as Facebook and Twitter.

> The social brain hypothesis doesn't explain all animal species—there are examples in the animal kingdom of highly social species with smaller brains—but it does seem to fit the primate tree fairly well.

> The relationship might be more complex than the hypothesis makes it seem. Intelligence is likely a factor, because more intelligent animals might find it more difficult, or at least more complicated, to get along.

> Nevertheless, we can't ignore the importance of our interactions with each other when we are trying to understand how our brains

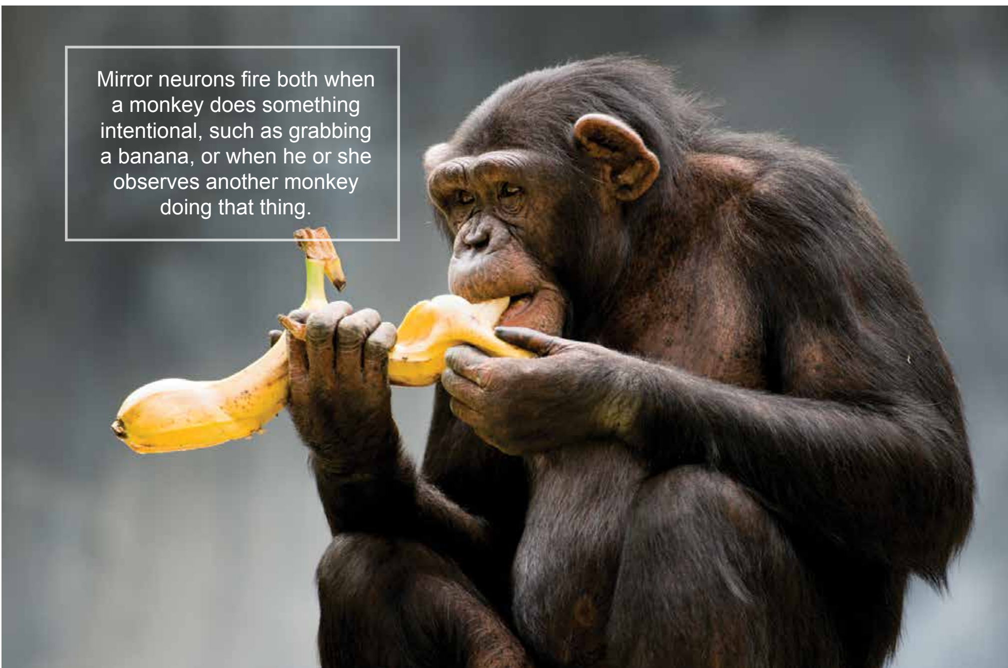
work. The danger of compelling "just-so" stories, however, is evident in the proliferation of myths surrounding mirror neurons.

MIRROR NEURONS

> In 1992, around the same time that Dunbar was publishing his first observations about group size and neocortex, scientists in an Italian lab were recording activity from neurons in the brains of macaque monkeys. They were trying to understand how these neurons support voluntary actions.

> These neuroscientists were recording directly from the motor cortex. They stuck an electrode into this brain region and tracked electrical signaling as their monkeys were performing goal-directed actions, such as grabbing a banana and eating it.

> They discovered that some cells in this region don't just fire when a monkey is grabbing its own snack; they also fire when that monkey observes another monkey grabbing a raisin. The



Mirror neurons fire both when a monkey does something intentional, such as grabbing a banana, or when he or she observes another monkey doing that thing.

observing monkey's brain is mirroring what's happening in the acting monkey's brain as the acting monkey achieves a goal.

- The existence of mirror neurons suggested to some scientists that we have evolved a special kind of cell that seems to enable us to imagine how and what another person or primate might be feeling and thinking. It is arguably the seed of empathy, and one might argue that the ability to know what someone else might be thinking is critical for survival in a social group.

- Mirror neurons aren't a morphologically different class of cells. They look just like the rest of the neurons in the motor cortex and elsewhere. But they behave differently. They have a different receptive field.

- All neurons have a certain stimulus set that causes them to fire. Visual cortex cells respond to different visual stimuli, auditory cortex cells respond to different sounds, and so on. Mirror neurons then fire both when a person (or a monkey) does something intentional or when he or she observes someone else doing that thing.

- The inference that it's the action of these cells that gives us empathy is still speculative. Maybe it is, but more likely, they are just cells in a larger network of neurons that underlies this ability.

- This is where the hyperbole begins. If these neurons are fundamental to empathy, then maybe they are the mechanism that fails in people who have problems with empathy and social understanding, such as individuals on the autism spectrum.

- Mirror neurons have been used by the media to explain why we cringe when we see someone hurt on TV or why hospital patients benefit from visitors. But unfortunately, the truth is much more complicated.

> Simply labeling cells as mirror neurons has led to a lot of confusion. Are we just talking about the human analogues of the cells discovered in the macaque, or are we talking about any cells whose receptive field includes some observation of another person's actions?

> Underscoring this confusion, we now distinguish mirror neurons (which we think of as the human analogue of the macaque cells) from the mirror neuron system (which is a distributed network of cells that are activated by observation).

> But the mirror neuron system is an interesting explanatory framework that we can use to describe activation in a number of different circumstances. The explanatory power of mirroring is compelling but also vague.

> We don't seem to need to activate our motor cortex to understand what a pianist is trying to express, because people who have damage to these regions don't lose the ability to recognize other people's intentions.

> There's no evidence that individuals on the autism spectrum have trouble understanding the actions of others, or imitating them. We still don't understand exactly what's gone awry in people with autism, but the problem is in their attribution of intention to the actions, which seems like it's at least a skill one level up from the activity of mirror neurons, at least as we currently understand them.

> We can't just check the mirror neurons in a person with autism. We can't stick an electrode in someone's brain and measure direct activity. But we can record from electrodes that have already been implanted in patients with epilepsy, for example. With this method, we have found that similar cells seem to exist in humans. We still don't know whether these specific cells are implicated in patients with autism.

> Mirror neurons might have lost favor among neuroscientists, but as their fame fizzled, another set of cells, this time morphologically distinct, have begun to take over the spotlight. Time will tell if their fate will follow that of mirror neurons or if they truly are one of the features of our brains that have given us our humanity.

> Von Economo neurons (VENs), named for the Austrian neurologist who discovered them in 1929, are also called large spindle cells, because that's what they look like. They are found in regions of your brain that are suspected to have evolved most recently.

MYTH

Hanging out with other people—socializing at the expense of working—is not as good for your brain as reading a book or doing some other intellectual task.

TRUTH

Our brain size exploded when we started living in groups, and the worst thing you can do to a baby is deprive him or her of social stimulation.

> These cells have been associated with complex human traits, such as a sense of self and awareness, and have been noted in other species who live in societies, such as elephants and dolphins, but not in many species of primates.

> Because they are morphologically distinct, we can see them under the microscope and therefore count them in different species and people (postmortem, for now). There might come a time when our imaging techniques are so sophisticated that we can actually see what they do in a living brain.

> Von Economo cells are abundant in 2 regions in the human brain: the anterior cingulate cortex and the frontoinsular cortex. These parts of the brain have been implicated in functions that are distinctly humanlike, such as our appreciation of music, ability to

recognize ourselves, subjective awareness, and ability to resolve inner conflicts between different desires.

> In an elegant model, neuroscientist Bud Craig has proposed that the insula—the insular part of the frontoinsular cortex—is intimately involved in our subjective awareness. He notes that insula activation in neuroimaging studies has been found during a wide variety of tasks, including the moment of conscious recognition, decision making, and self-recognition, which are features of what most people consider human consciousness.

> Craig suggests that what ties these experiences together is our awareness of them—that the insula is involved in gathering information from across the brain and giving us a sense of our self in the present moment.

> We don't know how accurate his model is yet, but we do know that one thing that distinguishes the frontoinsular and anterior cingulate cortex from other parts of the brain is the density of von Economo neurons.

> Because of their size, morphological characteristics, and connections, Craig and others think that they are particularly suited to transmit highly integrated information about our emotional state and behavior quickly. They might be the key to how we are able to become subjectively aware of our own feelings, thoughts, and actions.

> Von Economo neurons are plentiful in adult humans. They are scarce in infants and grow in number between ages 1 and 4. They are also present but scarce in gorillas, bonobos, and chimpanzees. They haven't been found in macaques.

> Patients with frontotemporal dementia (FTD), who lose awareness of their own emotions and self-consciousness, show a progressive and relatively specific degradation of von Economo neurons.

Symptoms of this disease include deficits in social and emotional self-awareness, theory of mind, moral reasoning, and empathy.

> While mirror neurons seem to play a role in understanding and imitating others, von Economo neurons are thought to be important in our ability to know ourselves. Both knowledge sets are important for social interactions.

> Because Von Economo neurons are implicated in social skills, empathy, and self-awareness and because they develop and mature when children are between 1 and 4 years of age, neuroscientists have wondered whether the symptoms of autism spectrum disorders might also stem from problems related to von Economo cell maturation. But a few postmortem studies of the brains of adults with autism showed no differences between their von Economo cells and those of healthy controls.

> Time will tell if von Economo cells will hold the key to much of what makes us human or if they will fade back into the background the way that mirror neurons have.

SUGGESTED READING

Allman, Watson, Tetreault, and Hakeem, “Intuition and Autism.”
Craig, “How Do You Feel—Now?
Hickok, Gregory. *The Myth of Mirror Neurons*.
Santos, Uppal, Butti, and Wicinski, et al, “Von Economo Neurons in Autism.”

QUESTIONS TO CONSIDER

1. How big is your effective social circle? What do you do to maintain it?

2. Why might social experiences be so critical in terms of shaping the brain?

23

IS YOUR BRAIN UNPREJUDICED?

You might not be racist, but your brain likely is. Prejudice is ingrained, and our behavior can be affected by biases of which we're not aware. These implicit biases are particularly important to consider when we are evaluating actions that happen quickly, instinctually, or automatically. When adrenaline is pumping through our bloodstream and we're in fight-or-flight mode, biases can hijack our rational minds and lead us to behave in ways that are uncharacteristic.

IMPLICIT BIASES

> Our brains have evolved to take many shortcuts, and one of the negative consequences of this is the fact that we tend to make automatic, unconscious inferences about people who are not like us. Even if you consider yourself broad-minded and accepting, it's coded deep within your nature to harbor prejudice.

> You are aware of your explicit biases—attitudes toward a group of people that you consciously acknowledge. But implicit biases are different. They are the products of subtle cognitive processes of which we are often unaware and aren't under our intentional control.

> Implicit biases can be tested in various ways and have been shown to exist on the basis of race, ethnicity, nationality, gender, social status, and other categories. One way that scientists measure implicit bias is called sequential priming: When 2 concepts are

related to each other in your memory, presenting one of them will prime the other. It will make it easier for you to recall or recognize the second item.

> Researchers have also measured implicit bias using neuroimaging techniques, tracking brain waves and activation of regions of the brain involved in emotion, social interactions, and conflict monitoring. They've found that when a person is exposed to a stimulus that he or she finds threatening, such as a gun, the amygdala is activated automatically.

> The amygdala has several functions, one of which is to ensure that emotional events are better recalled than neutral ones; it jumps into action when we feel threatened or fearful. In studies of implicit bias, scientists have found that when participants are shown images of black faces, for example, people who show implicit biases will show greater amygdala activation when viewing these faces than when they're looking at white faces, for example.

> But neuroimaging results aren't interpretable unless we understand much of the underlying behavior. And perhaps the most popular way to uncover implicit biases behaviorally is via the implicit association test (IAT), which was developed in the 1990s and has since become a crucial tool in social psychology research. Basically, the IAT pits 2 competing responses against each other, forcing you to suppress interference if you have a bias.

> The IAT works by assessing your implicit associations—essentially whether you have made connections between certain attributes, even if you are unaware of them. For example, do you associate science with the male gender, even if you respect many female scientists? The IAT can bring these kinds of unconscious biases and stereotypes to light.

> We know that memories of things that we're not consciously aware of can affect our behavior. The premise of the IAT is that, in the

same way, associations that we make implicitly can change how we act and the types of attitudes that we display.

> According to the IAT, most white people in the United States show an implicit preference for whites over blacks. But only about 50% of black people tested show an implicit preference for blacks over whites. Most people prefer young people to older people no matter how old they are themselves.

> But despite the widespread use and popularity of the IAT, it does have its detractors. Critics point to the fact that studies have found inconsistencies in an individual's scores across multiple test sessions. This is problematic if the test is supposed to detect biases that we carry around with us all the time.

> A simple manipulation—for example, thinking of positive African American role models—before taking the test can result in a smaller bias score on the race IAT.

> Other studies have shown that bilingual people show more bias when taking the test in their native language versus in their secondary tongue. Time of day might even make a difference, as tests administered in the morning tend to show less bias than tests taken in the afternoon or evening.

> But we shouldn't disregard the IAT altogether. This flexibility in terms of showing bias might be a reflection of what is actually going on in our brains: We might harbor implicit biases, but they are also fairly malleable, depending on the context.

MYTH

You are not prejudiced.

TRUTH

Our brains have evolved to take many shortcuts, and one of the negative consequences of this is the fact that we tend to make inferences about people who are not like us automatically and unconsciously.

- In fact, when it comes to our biases, context matters a lot, because biases depend on how we define our social group. One way of grouping ourselves is by skin color, but at a baseball game, we might group ourselves by team, rather than by race. The same can be true of religious denominations and political leanings, for example.

UNDERSTANDING BIASES

- Stereotypes are beliefs about attributes that are thought to be characteristic of members of particular groups. For example, opera singers are overweight.

- Stereotypes can then lead to prejudice, which is a negative attitude or emotional response toward a certain group and its individual members. I don't like opera singers, for example; they are gregarious, loud, and egocentric.

- Stereotypes and implicit biases are thought to reflect different underlying neural processes. Implicit biases seem to involve an amygdala-driven learning system when the bias involves some assessment of threat. That's why they are often learned during emotional experiences, often after only one exposure, and why they can persist and be difficult to extinguish.

- Stereotypes, by contrast, result from conceptual learning, based in the temporal lobes and the prefrontal cortex. It takes time and multiple repetitions to ingrain stereotypes, and like any habit, they can be hard to break. But studies have shown that people can successfully overcome stereotypes by monitoring their behavior and consciously trying to weaken the stereotype.

- Why are we prone to stereotyping and prejudice in the first place? Why can't we just evaluate every situation rationally and uniquely, rather than being influenced by past associations?

> Our brains are prone to making shortcuts. We can't possibly process all the stimulation available to us in a given situation, so we look for regularities or information that can help us choose how to behave. Given this natural tendency, categorizing people is one shortcut that our brains can use to cope with the complexity of social interactions.

> This may help us understand why stereotypes have persisted throughout the course of our evolution, despite the fact that they cause so much suffering.

> We live in a complex environment and are constantly bombarded with information. And just as our senses have to take shortcuts to help us process all this info, these same shortcuts might also be useful when we're assessing each other.

> The cognitive miser hypothesis suggests that stereotypes simplify our social environment so that we can choose our interactions more quickly and efficiently.

> Another idea is that we use stereotypes to identify with and fit into a social group. We emphasize the positive aspects of the group we want to belong to while at the same time differentiating ourselves from the group we don't belong to by tracking their negative features. This idea stems from social identity theory, the idea that we craft our social identities on the basis of the groups to which we belong.

> The pressures that shaped our brains into their current marvelous state were largely driven by our social environment, so it's no surprise that we are particularly attuned to evaluating others as friends or foes. The problem is that what we are taught is not always true, especially as generations change.

> We are born to prefer members of our own "group." But this doesn't mean that we are born with specific forms of prejudice. For example, we don't seem to naturally segregate groups by skin

color; that distinction is taught. By some very simple manipulations, experimenters can alter the way that you group people into “us” and “them” categories.

> All of us belong to multiple different groups, allowing us to categorize ourselves in many ways: by ethnicity, gender, generation, political leaning, and so on. Simply by emphasizing a way of categorizing, researchers can pull you from an out-group and into an in-group.

> Implicit does not mean innate. Just because a bias is unconscious doesn’t mean it wasn’t taught. Studies of children show that biases develop over time with the accumulation of experiences.

- We are especially prone to laying down biases after emotional experiences. This is how implicit bias can result in discrimination.

- Arguably the most powerful force creating implicit biases is systemic racism: living in a culture in which bias is prevalent. We are social creatures, finely tuned to the attitudes and opinions of those around us, as our brains have arguably evolved to allow us to live in relatively large social groups, at least compared with our primate cousins.

- So, implicit biases can be influenced by our experiences, parents, emotions, and society. Another connection that some researchers have drawn is between bias and our need for self-validation; in other words, maybe stereotypes feed our ego and help us build psychological defenses. Categorizing others makes us feel better about ourselves, in line with our self-serving bias.

- There is evidence that we have an implicit ego-building bias: We prefer our own in-group, whether it's defined by the sports team that we support, the college we attended, the religion we follow, or the color of our skin. We implicitly prefer people, places, and careers that match our identity in some way.

- There are many ways in which biases and stereotypes lead to social ills rather than social cohesion. Stereotypes can prevent us from achieving a more complex understanding of others—they get in the way of critical thinking. And of course they don't represent all or even most individuals in a particular group.

- When they enhance our egos at the cost of devaluing others, stereotypes can become the basis for prejudice and discrimination that erodes the fabric of society. They maintain systems of privilege and injustice and can block us from understanding how others really are, rather than how we think they are.

- The strength of our biases can shift depending on what state of mind we're in, and now there's evidence that when we're in a

stereotyping state of mind, it's not just critical thinking that suffers. Creativity does, too.

WHAT CAN WE DO ABOUT IT?

> Our fast, automatic, intuitive thought processes can help us navigate a complex world quickly and efficiently but can also lead us astray. In contrast, our slow, thoughtful, rational minds can help us become a civilized society, but this cognitive system is lazy, as Daniel Kahneman has pointed out, so we need to engage it deliberately.

> Tests such as the IAT are designed to measure fast reactions over slow thinking. The good news is that interventions—such as the simple tool of thinking about a role model who happens to belong to a group we're biased against—can be effective in quieting down and even changing our automatic responses.

> We don't need extremes of political correctness to address this problem in society; instead, awareness of our tendencies, instincts, and reactions can go a long way toward fixing the problem.

> Intergroup interactions are some of the most successful ways to reduce implicit and explicit biases. These interactions challenge stereotypes by increasing knowledge about members of the out-group, humanizing them, reducing anxiety related to interactions with them, and increasing empathy and perspective-taking. Even just thinking about a positive interaction, in which a member of the out-group becomes an ally, can reduce bias as measured by the IAT.

> Racism, implicit bias, and stereotyping are ingrained in our society and leave a trace in our brains as a result. But the good news is that there are effective interventions, and being motivated to override automatic instincts is usually enough to stop us from behaving badly.

SUGGESTED READING

Amodio, "The Social Neuroscience of Intergroup Relations."

Devine, Forscher, Austin, and Cox, "Long-Term Reduction in Implicit Race Bias."

QUESTIONS TO CONSIDER

1. Why would the brain have evolved to quickly categorize people as friends or foes?

2. What can we do to overcome the inherent biases that our experiences have ingrained in our brains?

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DOES TECHNOLOGY MAKE YOU STUPID?

Since the rise of the Internet, there have been many warnings that technology is making us stupid. But is there any truth to these claims? Technology opens new frontiers to humans, and it's natural for people to have concerns and even anxieties about what may happen as we explore those new frontiers. But when it comes to the question of whether today's technologies make us stupid, based on the evidence, the answer is no. Rather, our brains are adapting to the new skills that technology will demand of us.

TECHNOLOGY AND FOCUS

> Probably the most common fear is that access to smartphones is killing our attention span, or how long we can focus on something. Do we really mean that smartphones are killing our ability to focus, or is it that our tolerance for boredom has decreased?

> What evidence do we have that the same person who flips through social media quickly cannot focus his or her attention for longer periods of time on other tasks? The same people who are accused of being addicted to social media, who won't spend more than a few seconds on any given post, can still get lost in a novel or a movie.

> You might say that we're talking about 2 different skills: Getting lost in something interesting is not the same as having to focus on

a topic, book, or paper that is less about entertainment and more about education. From that perspective, attention span is more a question of fighting boredom, or keeping oneself actively engaged with the material at hand, rather than relying on the presenter to hold our focus.

> What about the idea that people in the past were able to tolerate boredom much better and that smartphones and other tools have made us less able to control our own minds? Most people can focus on things for hours; it's just that those things that keep our attention change with each generation, and with each individual. It depends on what we find entertaining, whether it is musical composition or comparing vacation photos.

> Doctors' offices have had magazines in them for decades because waiting, with nothing but our minds to occupy us, is an aversive state for many people. This is a phenomenon that's been around a while—not one that emerged in the Internet age.

> In these instances, we confront a basic fact about the way our brains are wired: We get stressed when we feel as though we aren't in control.

> John Eastwood at York University has proposed that boredom is a function of feeling that you want to engage in a satisfying activity, but for some reason, you can't. And you attribute that reason to something in the environment, which you can't control.

> The doctor's waiting room or the long flight are situations in which you don't have control over the main activity you're involved with. To regain some control, and to minimize this aversive state, people turn to some diversion. Maybe it used to be a magazine while now it's a smartphone, but the human tendency is essentially the same.

> Being bored is considered shameful by many people; many people look down on people who are easily bored, seeing it as a sign of a lack of intelligence. But boredom can actually lead to creativity.

- The problem now may be that we have fewer opportunities to learn how to entertain ourselves using only our minds. With smartphones and tablets, the range and quality of the entertainment at our fingertips has changed dramatically, which means that it's easier to assert control by turning to our devices when we're feeling bored.

- Some would argue that checking social media doesn't compare with reading *Anna Karenina*, but the truth is that we have that choice: The novel is just as accessible as any other application or game. Why don't we always choose literature over status updates?

- The answer is different for different people, but for many people, the rewards of getting lost in a great novel take a bit longer to reap. You need time to get lost in the story, and having to interrupt your experience when the flight lands or the doctor calls you in can be jarring—reminding you of the fact that you're not in control of your mental state.

- But checking out a photo of your niece or reading a text message from a friend can fit into any tiny time period, giving you a tiny sense of accomplishment when called away from the activity, rather than reminding you that you're waiting on someone else.

- John Eastwood worries that smartphones have made us less skilled at tackling boredom, putting us on a slippery slope in which we tolerate it less and less. Not having to submit to boredom, we don't learn how to eliminate it using just our thoughts. He has likened it to an addiction, suggesting that the more you do it the more you feel the need to do it.

- You might have come across headlines purporting that checking social media is addictive—that people behave as if they are on drugs and that the brain looks like it does when you take cocaine. This is an exaggeration.

- The dopamine-mediated reward system can get activated—which is where these comparisons come from—but dopamine isn't just a reward chemical, and the regions involved don't just light up when you're enjoying yourself. It's more like a salience network, activated when something in the environment is worth paying attention to.

- You probably recognize that checking social media is not as engaging as getting lost in a great novel, and we can see the difference in how the brain is activated, too. But checking social media can be more rewarding than just waiting for something to happen, and being interrupted while on your phone might be less aversive than if you were lost in a novel. So, you'll see more of the dopamine system activated when flipping through some app than you will if you're just sitting in the doctor's office, bored.

- But studies are also showing that instead of the Internet making people more distractible, it's likely that people who are more distractible to begin with struggle more with the nefarious aspects of technology use.

TECHNOLOGY AND INTELLIGENCE

- Does computer use make you less intelligent and more reliant on technology? Some studies have shown the opposite. For example, one study from 2010 showed that people who use computers more also tend to show better performance on certain cognitive tests. Researchers found that frequent computer use was associated with better overall cognitive performance across adulthood, even when they accounted for age, education, sex, and health.

- You might argue that computers are generally used more by smarter people, so one would expect frequent users to perform better on these tests, simply because they're smarter. But even when the researchers controlled for intelligence, they still found a correlation between computer use and executive function—specifically, greater speed at switching between tasks.

> MYTH
>
> Technology will make you stupid.
>
> TRUTH
>
> Spending a lot of time doing anything will rewire your brain, but the uses of technology vary widely, and some of them actually make us smarter.

- This finding is in line with other studies that have also found an association between more frequent computer use and better cognitive outcomes in older adults. In fact, people who have fewer intellectual and educational advantages seem to benefit the most from computer use.

- In another large study, computer use was found to be associated with a 30% to 40% lower risk of incident dementia—that is, the men who were diagnosed with dementia once the study was in progress but not before.

- Even a relatively passive activity, such as browsing the Internet, engages the prefrontal cortex, where our executive functions, such as reasoning and decision making, reside. But older adults

who are new to the Internet don't show this same pattern of activation; they just show engagement of parts of the brain used while reading. It seems that, with experience, Internet use can change how the brain is engaged during browsing.

> Time is a factor. Interventions in which computer use has been used as a treatment for up to a year have generally failed to show positive effects in older adults. But over the course of many years, the efforts seem to pay off.

TECHNOLOGY AND MEMORY

> Many people complain that knowledge is superficial these days—that our memories are harmed by the fact that we don't need them as much as we used to. Have we made a Faustian bargain with computers, building their memory at the cost of our own?

> Research has shown that when people think that information will be available to them by some other means in the future, they don't remember it as well. The effort we make when trying to learn information plays a big role in terms of our ability to recall it later.

> The availability of information via search engines has made us feel as though it's unnecessary to remember almost anything. Perhaps the skills that we need are those that involve learning how to find the information, rather than remembering its content.

> Google is changing how we remember. We are better at remembering where to find facts than we are at remembering the facts themselves. But maybe, as the number of facts available to us skyrockets, this skill is actually more useful to us in the long term.

> The brain is both malleable and adaptable. As our technological environment changes, our brains develop different skills that help us meet the distinctive challenges of the new environment.

TECHNOLOGY AND SOCIAL BEHAVIOR

> Initially, people who spend more time on social media do spend less time in face-to-face interactions, but even that is changing. In 1998, Robert Kraut and his colleagues published a study of 73 households that had just gotten access to the Internet. The study made headlines because it showed that the more these families used the Internet, the less they communicated with each other. Their social circles declined, and they became more depressed and lonely. The Internet was hurting their social lives. Kraut called it the Internet paradox.

> But in 2002, Kraut and colleagues published a follow-up study that didn't generate nearly as much attention in the press. The study reported that 3 years later, the negative effects of the Internet had dissipated in the original families, and in a larger sample of 406 new computer and television users, using the Internet actually improved communication, social involvement, and well-being.

- The best results were seen in people who are naturally outgoing. Kraut and colleagues call this the rich-get-richer effect: They found poorer outcomes for people who were less social or had less support. And people who are shy tend to have fewer friends on social media.

- But contrary to the idea that social media disconnects, a study from 2012 showed that increasing the number of times a person posts on Facebook correlates with feelings of greater connection to his or her community. And this intervention—forcing participants to post more regularly—was especially beneficial to people who are naturally shy.

- Social media gives us new ways to stay in touch and connect. And we learn to adapt our own online behavior if we find that these technologies are harming us. If Facebook makes you sad, you'll learn to use it differently, or not at all.

- Having online identities affects how we think about ourselves, in part because we now have access to much more information about our past.

- Technology is a tool that can dramatically expand our capacity to store and retrieve information. If you think of the Internet as an extension of our memory, for example, then there's no question that it is a vast improvement over the capacity of any individual human brain. But some people still balk at the idea that technology can enhance certain characteristically human functions, such as creativity.

- We already know that music algorithms can write or at least evaluate pop songs, and these algorithms can even make human composers more creative, giving them access to many more soundscapes and experiments in music than would be possible without them.

SUGGESTED READING

Almeida, Yeap, Alfonso, Hankey, Flicker, and Norman, "Older Men Who Use Computers Have Lower Risk of Dementia."

Sparrow, Liu, and Wegner, "Google Effects on Memory."

QUESTIONS TO CONSIDER

1. Do you think we should limit screen time in children? Teenagers? Adults? The elderly? Why or why not?

2. What kind of technology has led you to think in a different way, or even made you smarter?

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